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TECHNIQUE FOR OBJECTIVE STUDIES OF THE VOCAL ART[1]

BY

MILTON METFESSEL

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Primitive music; conclusions; references.

In general, the present purpose is to develop an adequate setting in which investigations of the vocal art may proceed. This will involve (1) a description of simple and accurate apparatus, constructed or adapted during the progress of the investigation, and (2) recommendations for technique of procedure for various phases of the whole problem.

Extensive tests were made to determine the practical success of the apparatus and actual results achieved are used as a criterion for the technique described. These results contain much suggestive material relative to the principles of emotional artistic singing, but await the verification more extended studies may give. They will be published subsequently under the auspices of the National Research Council.[2]

[1] The work throughout the following pages was accomplished with the coöperation of Professor C. E. Seashore.

[2] At the time of reading of the proof of this article there is at hand material on the following problems and devices:

1. Rôle and status of the vibrato in artistic singing. 2. Origin of the vibrato. 3. Definition of the nature of the vibrato, tremolo, and trill. 4. Types.

Historical Summary

Seashore (8) has outlined the general field of psychophysical measurements in the expression of emotion in music and has pointed out the possibilities of his original method of attack. *Schoen* (6) started the experimental work in this field, making his contribution from phonograph records operated at low speed, the pitch being read on the Seashore tonoscope.(7) Schoen, in studying " The pitch factor in artistic singing," covered the following subjects under " Intonation ": attack and release of tones, sustaining of tones, effect of vowels, movement from one tone to another, relationship between rise in pitch and rise in intensity, and sharping and flatting. In his work on the vibrato, he considered its relationship to artistically effective singing, constancy in rate, relation of intensity and pitch fluctuations, and the relation of absolute intensity of a tone and range of the vibrato.

Kwalwasser (3) next undertook a phase of Schoen's work with more intense concentration of effort on the crescendo. Kwalwasser used the Seashore tonoscope, the disc lever recorder of *Merry,*(4) and concluded with a device for photographing sound waves which utilized a motion picture camera, a phonelescope,[1] and as a timing mechanism, a light interrupted by either

5. Causes of the variation in extent of pitch and intensity and in rate of oscillation. 6. Relation of fluctuations of 25–50 per second superimposed on the vibrato. 7. Effect of the emotions on the vibrato. 8. Development of the vibrato through childhood and adolescence to maturity. 9. Comparison of the artistic vibrato with the untrained vibrato. 10. Results of general vocal training. 11. Comparison of the voluntary and automatic vibrato, with a bearing of the intentional teaching of the vibrato. 12. Character of the vibrato in the attack and release of tones. 13. Racial comparisons. 14. Individual and sex differences. 15. Correlations with psycho-physical and physiological measurements, including that of musical ability. 16. Determination of what constitutes a desirable vibrato in a given situation. 17. Records of breath pressure and breathing muscle movements used in the determination of many of the intensity factors, since it is a well known fact that the louder the tone the stronger is the blast through the vocal cords. 18. Synthetic vibratos made from siren discs, with different sizes of holes and different spacings between holes for the intensity and pitch factors respectively.

[1] The phonelescope is a convenient type of optical lever manufactured by Herbert Grove Dorsey, Gloucester, Mass. A vibrating diaphragm moves a tiny mirror, the mirror vibrating synchronously with the movement of the phonelescope diaphragm. A light is reflected from the mirror of the phonelescope to a film, the light point vibrating vertically as the phonelescope dia-

a serrated disc or a vibrating tuning fork. With this the pitch fluctuations, rate of pulsation of the vibrato, and the pitch-intensity relationship in the crescendo were measured.

Herzberg (2) used this apparatus in photographing and reading the pitch and time variations in McCormack's rendition of "Annie Laurie."

Simon (10) made the first basic study with regard to the wave-to-wave pitch fluctuations of the human voice and various musical instruments. He made use of the Seashore tonoscope (7) as a means of constant passage of film for photography with the phonelescope.

I. Critical Study of New and Adapted Apparatus

Apparatus previously constructed in the Iowa Psychological laboratory had been made with a view to uniting all the advantages of apparatus used in studies such as these by former workers in the field. But tests applied to the apparatus of *Merry* (4) and *Kwalwasser,* (3) in ascertaining the accuracy necessary for studies in vocal expression, showed that these devices, while serving some purposes, were not sufficiently refined for this type of work.[1]

There are a number of other sound photography devices to be found in the literature, notably among which are those of

phragm vibrates horizontally. The diaphragm vibrates sympathetically with the sound waves impinging upon it. The light point on the film copies the diaphragm's movements in greatly magnified form.

[1] The chief difficulties in the disc lever recorder of Merry arose from the fact that the smoked paper upon which the recording was done was driven by a belt at a very slow rate. While this device utilized a serrated disc on the same shaft as the phonograph record from which the pitch was being recorded as a timing mechanism, the slippage of the belt driving the drum with the recording material caused a variation in its speed between the marks made by the timing device. To this fact was added the objections arising from smoking the paper, confinement to a short length of recording material, a gradual bending of the sound wave line due to the spiral method of recording, and difficult definition of wave lengths.

Kwalwasser's phono-photographic apparatus, in making use of a motion picture camera, used an instrument which drove the film through irregularly. This device used a flash of light as a time line, and a sharp enough point for precise measurements was difficult to obtain. Simon's apparatus was confined to eight-foot film lengths traveling at a rate greater than that required in these researches.

Miller (5) and the research laboratories of the American Telephone and Telegraph Company and Western Electric. (1) Our needs made it necessary to construct as simple an apparatus as possible, adapting it to photography from phonograph records and field work.

Types of Technique: (1) *With Phono-photographic Apparatus*

Laboratory type. The main parts of the laboratory type of the phono-photographic device used in this problem and shown in Fig. 1 are simply (a) a large drum about which standard motion picture film winds after (b) photographing the lights reflected in vibratory motion from two phonelescopes, the one a graphic representation of sound waves from an unknown pitch of the

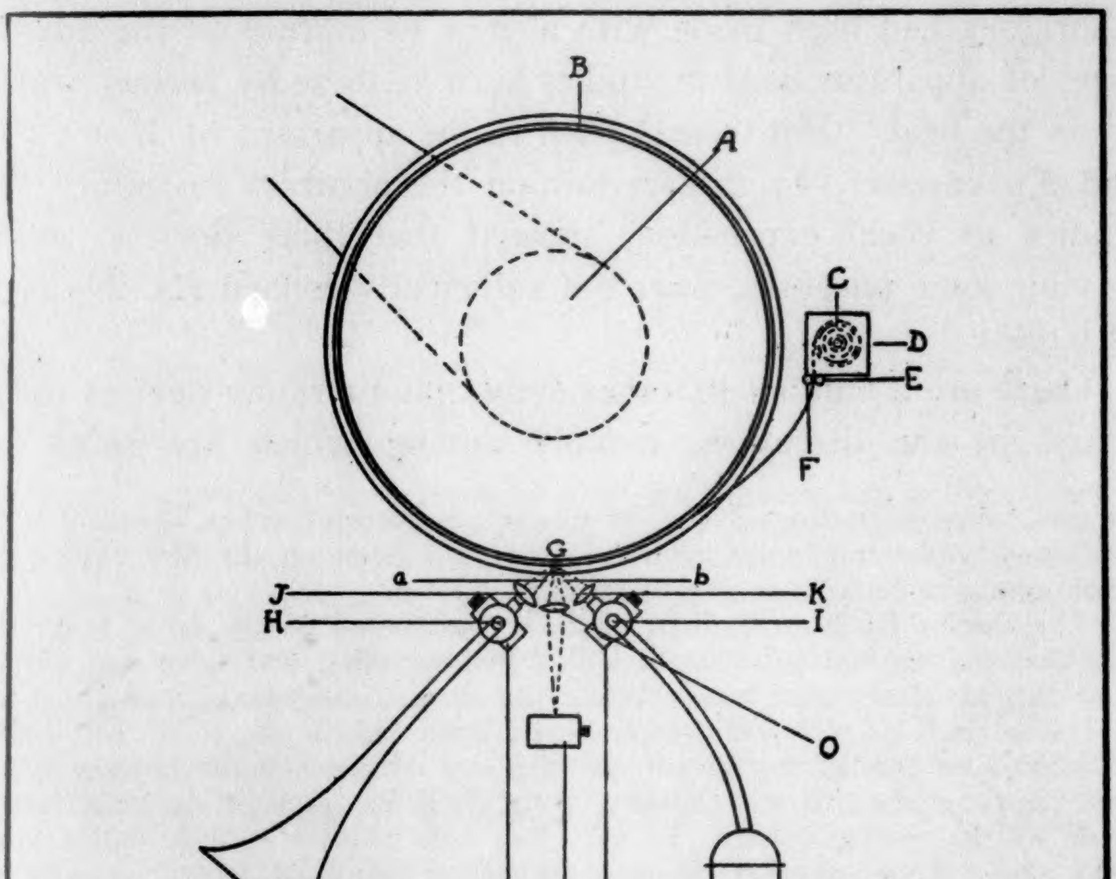


Fig. 1. Essential parts of phono-photographic apparatus. (Laboratory type.)

voice or other vibrating instrument, and the other from a known source of a 100 d.v. electrically driven tuning fork, to be referred to as the " time line."

Referring to Fig. 1, the large cast iron horizontally revolving table (A) is turned by a motor, with the advantage of the fly wheel effect of regularity of movement. A hoop is built up about its outside edge, the width of the film in height, and some 60 cm. in diameter. The movable table (A) with the drum (B) revolves in a good bearing.

Eastman high speed standard motion picture film (C) is wound about the drum (B) when revolving, providing a rapid and regular passage of film past the point of photography. The film is passed from the motion picture negative film box (D). Two rollers at the exit of the film box (E and F), with springs attached, press against the moving film, thus insuring a tight winding about the drum.

Beams of light (a and b) are reflected from the phonelescopes (H and I), and are brought to a focus on the film at point G[1] by lenses (J and K) placed between the phonelescopes and the film. The beam of light issues from a tiny aperture in light housings (L and M) within which are conventional 16–18 volt automobile electric lamps, through which 25–40 volts are forced, producing a great brilliancy per unit area of concentrated filament.[2] The direct current, 110 volts, is ordinarily used and stepped down. A third electric lamp (N) is used with the lens (O) to concentrate a stationary light point which produces a straight line on the film.

A conical horn (P), or a flexible speaking tube, communicates the sound waves from the unknown pitch source to the diaphragm of the phonelescope (H). An electrically driven tuning fork (Q)

[1] A shield placed tangent to the drum was a part of the apparatus for a time, since it was thought that the lights would shine through the transparent film. But it was found that the lights could be adjusted to an optimal intensity which photographed on only the outer layer of film, when not more than 200 feet of film was used.

[2] The sockets for these lamps were finally eliminated because of their shortlivedness under the excess voltage, and the wires soldered directly on the bulb. This step proved to be a great saving in time and expense.

is sounded into the resonator (R) and the sound waves strike the diaphragm of the phonelescope.

Fig. 2, A, presents the finished product in its actual size. There are the two separate curved lines made by the vibrating lights from the two phonelescopes crossing and recrossing the straight axis line. *Miller* (5) introduced the plan of a base line in phono-photography. Any given intersection gives a sharp point of reference for exact readings. These points of crossing, when they represent successive wave lengths, will be referred to as "critical points of intersection." The wave length of the sine curve, from the 100 d.v. fork, is easily identified. The irregular curve made by the artist's voice likewise repeats itself, each repetition being one wave length. The number of waves made by the singer which occur in the distance of .01 sec. might be counted in terms of tenths of a wave. This when multiplied by 100 gives the pitch in terms of d.v. during that interval.

This plan eliminates the dependence on a constancy of speed of film over long distances of film, and substitutes for it a regularity of movement. Should the drum revolve at a slowly changing rate of speed, the change would be produced on both the known (the tuning fork) and unknown (the voice) frequency of vibration. This variation should be well within the error involved in reading pitch.

The film may pass the point of photography from less than one to more than twenty feet per second. This advantage is apparent in recording the voices of men and women, the latter requiring the greater rate of film passage.

The three lights and the motor are turned on and off by a single switch. The intensity of the light has ample time to build up while the drum gathers speed.

Two pictures may be taken on the same film. The lights are focussed about two-thirds of the way down the film for the first exposure, and the film is then driven through upside down.

The operation takes place in a dark room. A faint green light is used which aids the experimenter and does not affect the film.

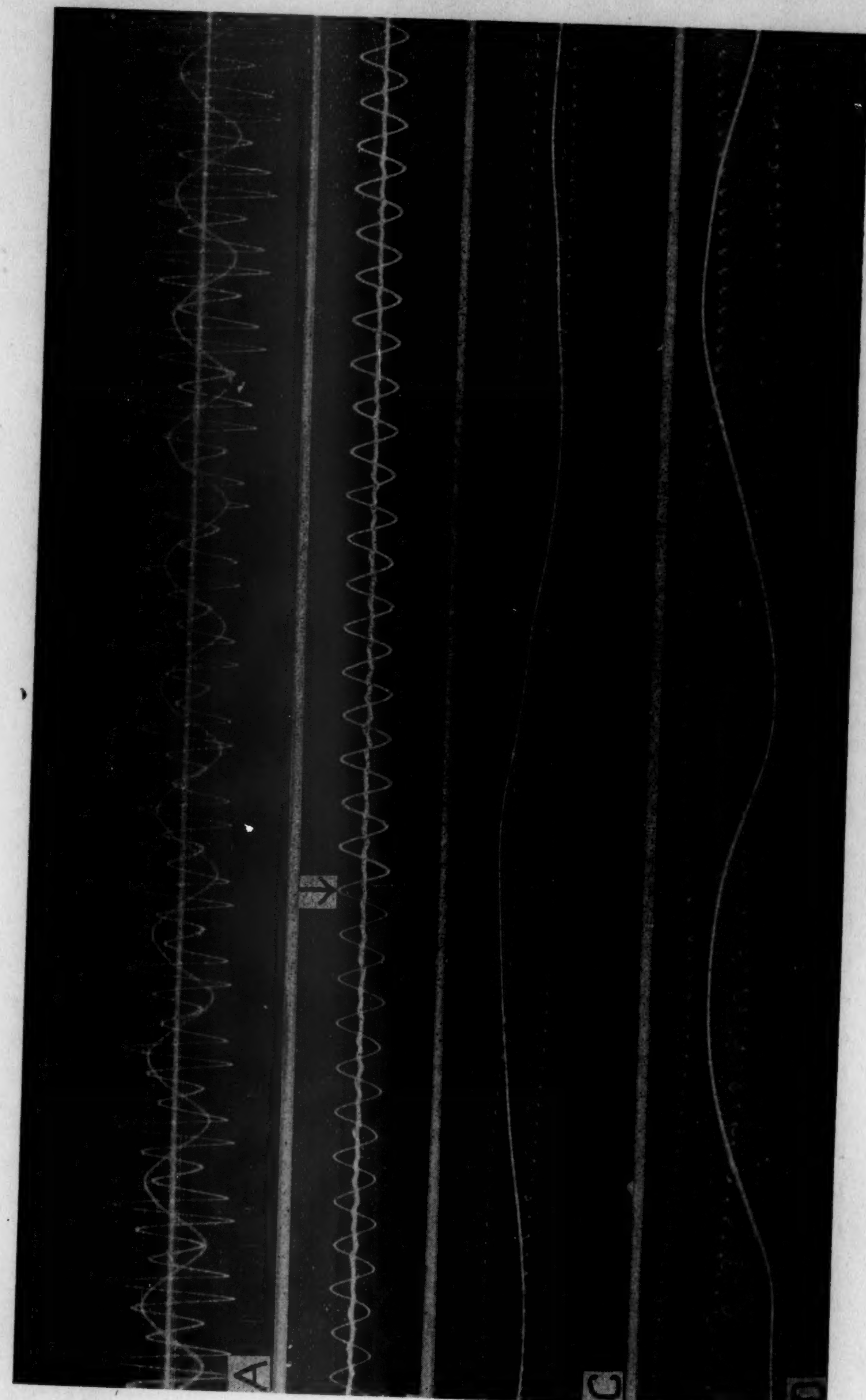


Fig. 2. Typical films

The film is kept in light-proof boxes save when being driven past the light points and wrapped around the drum.

Adaptation to studies in intensity and timbre. In view of the fact that harmonic analysis of the sound wave made with the phonelescope would be entirely inadequate due to distorting resonance regions of the membrane, when studies in intensity and timbre follow the many yet unsolved problems in pitch and duration, more sensitive optical levers now known to exist may be substituted for the phonelescope vibrating from the sound waves of the voice. The rest of the apparatus will remain intact.

Adaptation to phonograph record photography. Seashore (8) has pointed out the value of phonograph records in studies made in speech and song. The voices of the best artists may be brought into the laboratory and studied without the artist's awareness that his voice is undergoing objective scrutiny.

The tube at the entrance of the phonelescope (H, Fig. 1) admits of adjustment to either a speaking tube, conical horn, or phonograph tone-arm. Therefore to shift from direct photography of the voice to photography from a phonograph record, it is only necessary to attach the tone-arm. This arm is specially adapted by lengthening so as to reach from the phonelescope to the phonograph record and is adjustable for use on any make of record.

The phonograph record is immovably placed on the iron turn table (A, Fig. 1), being clamped upon a felt platform glued to the iron plate. Since the film is wound about the drum on the outside edge of the turn table, the record and film travel synchronously. Any variation in the speed of the one will be transmitted proportionately to the other.

The time-line cannot now be taken from a tuning fork because of a lack of constant relationship to the rate at which the phonograph record travels during photography. For this type of work no separate timing device is absolutely necessary. The circumference of the drum for each revolution is known, as is the original rate of recording of phonograph records.

However, the increasing circumference of the drum, due to

the effect of film winding about it continuously, might call for a more convenient device than a shift of all mathematical calculations for each subsequent revolution. A 77-toothed disc has been placed on the axle on which the turn table and phonograph record revolve. The teeth cut a magnetic field producing variations in the electrical current of the circuit of which the magnet is a part. The electro-magnet of a telephone receiver is used and a receiver of the same resistance attached to the phonelescope. The latter receiver is a part of the complete phonelescope outfit, and provision is made for attaching it so that the diaphragm of the phonelescope is the only one used. For increasing the amplitude, radio amplifying units are available. The 77 teeth are very accurately spaced and when cutting a magnetic field sound a tone in the phonelescope with a value of 100 d.v., assuming the original recording rate of the phonograph to be 78 r.p.m.[1]

Short films of one revolution of the phonograph record are used for testing purposes and for single tone photography. Only one phonelescope, light and lens is necessary for this type of work. The one light serves two purposes. When the light is at rest, it is permitted to photograph on the film for one revolution before the actual picture is taken. This gives a straight line throughout the length of the film. The vibrating light caused by the playing phonograph is photographed over this line. The effect is a base line at the center of the sound waves vertically.

The exposure of one and only one revolution of the moving drum is accomplished by placing a trigger on the under side of the iron turn table near the outside edge. When the desired revolution for photography is the next round, a heavy wire in the shape of a right angle is placed in the path of the trigger so that the trigger on striking it whips it down into an open wedge. This closes an electrical circuit, moving a magnet which permits the light to pass from the light housing. The trigger in passing

[1] The disc was cut with 77 teeth since this number gave the closest approximation of the distance traveled in .01 sec. by the phonograph record. 77 x 78 shows that 6,006 teeth pass a given point in one minute, while there are only 6,000 $^{1}/_{100}$ seconds in that time. This error is slight and constant.

again to complete the revolution strikes the other part of the right angled wire, breaking the circuit and cutting off the light.

Adaptation to records of bodily changes in singing and speaking. Fig. 2, C and D, are illustrations of this type of record. A parallel legend is exhibited of heart beat, breathing musculature, breath pressure, voice vibrations and time line. Another light, phonelescope and lens must be added to that shown in Fig. 1. The conical horn (P, Fig. 1) is replaced by a mask which encloses the mouth and nose tightly. It is connected by a rubber tube to the phonelescope. This provides for a resultant curve on the photograph of breath pressure and the vibrations issuing from the vocal cords. The third phonelescope communicates by means of a rubber tube with a pneumograph which records the movements of the breathing musculature, and in some cases, the heart beat. These latter pulsations are picked out on the breathing curve by an irregular jog which occurs at regular intervals. These devices vary the pressure of the air column against the diaphragm of the phonelescope, moving the mirror.

Fig. 2, C, is a snatch of the beginning of a crescendo sung by Lowell Welles, a trained musician, and Fig. 2, D, a section of the louder part.

Field type of phono-photographic camera. The original reason for having a drum as large as 60 cm. in diameter (Fig. 1, B) was the reduction of the error in reading wave-lengths in phonograph record photography. For proposed studies in primitive music or speech, where it is necessary to have a portable apparatus, the diameter is cut in half.

The field type camera therefore has a drum 30 cm. in diameter mounted in a reinforced suitcase. A crank is attached to the drum so the film may be driven through by hand. Otherwise the make-up is essentially that as described above and pictured in Fig. 1. The unit consisting of a single upright stand with the phonelescopes, to which the lenses are firmly attached, and the electric lamps lighted by radio " B " batteries, is fastened to the bottom of the case. At one side the 100 d.v. electrically driven tuning fork is mounted. The fork is connected in circuit with a

telephone receiver attached to the phonelescope, so a resonator here is unnecessary, although the sine curve is lost.

The case is light proof when closed, so that the film may be moved by the hand without exposure to extraneous light. A flexible speaking tube runs out from the box for the singer's or speaker's use.

Conversion of film data into pitch and duration. With the photography completed, and the film developed, it is necessary to proceed to reading the pitch and time variations. To do this it was requisite to devise some method of comparing the known tone (" time line ") with the unknown tone (voice).

Since the time line of 100 d.v. marked off distances on the base line on the film representing .01 sec. of the passage of time, it served two purposes. First, the number of complete vibrations of the unknown pitch could be computed in terms of the number of tenths of waves by counting this number in any desired interval. This when multiplied by the number of those intervals in a second, gives the pitch in d.v. of the unknown tone at that instant. Second, the duration of a tone or part of a tone could be computed by counting the number of .01 sec. distances occupied.

In order to facilitate the pitch readings, a simple apparatus was made with two slide rule glasses fastened together so as to permit the film to pass through it. The hair line on the glasses was always at right angles to the edge of the film. A magnifier attached proved of value. This device was slid along the film and rested upon the time line's critical points of intersection, thus aiding the eye in counting the number of waves and fraction of a wave in the time unit.

The operation of reading is performed in cumulative fashion. Its value lies in the fact that any gross error in reading will cause an apparent compensation in subsequent readings, and thus calls for a check-back, a re-reading and correction.

The task of reading the pitch of the waves on the films taken from phonograph records where the time line was omitted makes necessary the computation of the amount of film passing a given

point per second as would be co-incident with the theoretical speed of the phonograph record in the original making. The turn table on which the film and phonograph revolve is therefore theoretically divided into .01 sec. distances of the original speed of the phonograph record. At a circumference of 196.1 cm. which is the length of the film when tightly wound around the drum, and at an original speed of phonograph recording of 78 r.p.m., the value of the .01 sec. unit is 2.549 cm.

For reading in terms of .01 sec. distances with these films, a long, rectangular piece of glass a little wider than the film in length and equally divided by hair lines into 12 distances of 2.549 cm. each, is utilized. The glass is placed over the film and the number of waves in terms of .1 wave is counted as in the long length films.

In any type of pitch measurements of this character, the raw material is the wave lengths on the film record, or the distance on the film taken by a complete cycle of the sound wave. There is still another way in which these wave lengths may be conveniently changed into pitch than that mentioned above, viz., counting the number of waves in a given time unit. Where a constant passage of the film may be assumed, the wave length may be measured, and by the process of dividing the wave length distance into the speed at which the film travels, the pitch is ascertained. (Cf. *Simon* [10].)

The apparatus for wave length readings used in this work consists of a long, rectangular glass similar in dimensions to one just referred to above, which instead of being divided into distances of 2.549 cm., has hair line divisions of 1 mm. throughout its entire length. This glass and the film are placed in an apparatus so that the glass is on top of the film, and is adjusted so that the hair lines are exactly perpendicular to the base line on the film. With a high power reading glass the wave lengths may be read cumulatively from one critical point of intersection to the next with an accuracy of plus or minus .05 mm. as tests of accuracy have repeatedly shown.

With the degree of regularity of film passage which the appara-

tus has, to be discussed below, it is safe to conclude that one may expect in the case of long length films of direct and phonographic photography, an approach to constancy of film travel in one hundredth of a second. Any deviations from constancy in this unit has turned out to be well within the error involved in reading the waves in this unit of distance. This means that if wave length readings are desired they may be measured in units of .1 mm. and this divided into the rate of film passage as revealed by the known tone of 100 d.v. This, however, requires a separate computation for each .01 sec. distance. The value of these wave length readings lies in a much more frequent number of readings for a given tone.

As was mentioned above, it is possible to eliminate the .01 sec. time-line in the case of phonographic photography of long films. When the time-line is not used, the method of computing the increased circumference for each successive revolution is as follows: the distance would be increased each time around 2 x .33 mm., the thickness of the film, beginning at the point where the second layer of film reached the first on the initial winding. Since the film is under tension it is wound tightly around the drum. As an empirical check, the point where the film begins and completes each revolution may be marked by the exposure of a slit of light across the top of the packed film.

Separate reading devices for various speeds of phonograph recording are not entirely necessary, and this also applies to readings made on long length phonographic photography films when the time line is omitted. Since the .01 sec. unit is arbitrary, and the only requirement is that it be constant and known, compensations may be made mathematically so as to derive the correct pitch and duration.

Desirable method of reading. A definite recommendation was necessary in the matter of whether, for studies of artistic singing, to read each wave length distance or to count the number of waves in terms of .1 wave, grouped in .01 sec., .02 sec., .03 sec. or more distances. *Simon* (**10**) has shown that as far as the unit of grouping is concerned "if all that is desired is the

long-time fluctuations, then two or three of the individual measurements may be grouped; but if the short-time fluctuations are to be recorded, then the single units should be used." He further states that " if the grouping accomplished by the time-line method is allowable, then for exposure of longer than one second, the mechanical factors involved would indicate that this method be used." In order to make certain that the time line method was

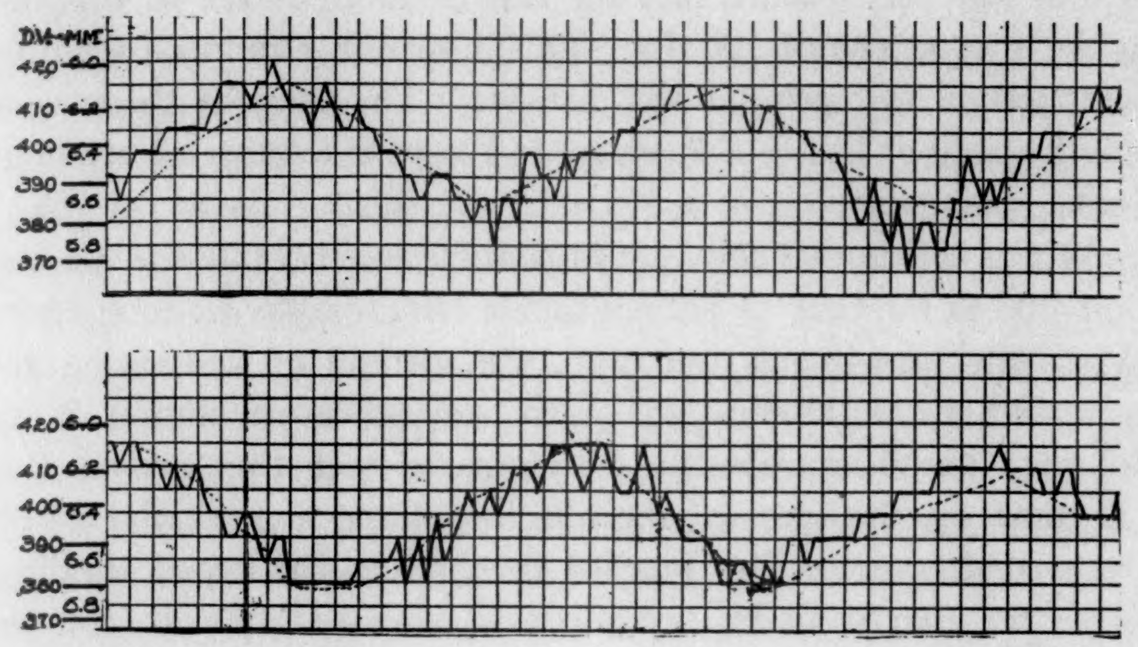


Fig. 3. The wave length readings in mm. are represented by the straight line, and the readings made by counting the number of sound waves in .02 sec. by the dotted line.

allowable, and which unit was the better, a tone was selected from McCormack's "Annie Laurie" phonograph record. It was read by the various methods mentioned.

Fig. 3 shows the comparison of wave length readings with those made by grouping within .02 sec., since the latter fairly smoothed out the more jagged wave-length readings.

The results obtained with .01 sec. as a unit took more time in reading than .02 sec., and give a more erratic appearance than the wave length method. It was further handicapped by the fact that since the steps in reading are in terms of ten vibrations instead of five in .02 sec. as a unit, the possibility of error per measure was double. Counting the waves in a distance of .03 sec. averaged the waves so that the pitch extent over the

wave length readings was materially decreased. However, as Simon also pointed out, the frequency of vibration alters the unit of grouping. For pitches below 180 d.v. readings in .03 sec. units proved adequate.

Fig. 3 shows that readings in .02 sec. at a pitch about 400 d.v. were quite as adequate as the reading of individual waves, in portraying the important factors to be derived in pitch and duration studies; such as the pitch extent of the vibrato, the mean pitch, and the duration of each complete oscillation of the vibrato. This unit of .02 sec. gave these same general advantages over other methods for pitches as high as 800 d.v.

In this connection the "aufgabe" in reading should be fully understood. *Simon* (10) has referred to subjective factors in reading pitch. This factor enters into the readings in .02 sec. in the matter of making a choice in judging tenths of a wave length. Oftentimes the reader is not fully sure whether to call it, say, six-tenths, or seven-tenths. So the following guiding principle was used to aid this determination: Fit the readings into as smooth a vibrato oscillation as possible in cumulative reading. This was justified by its results in Fig. 3.

Tests of accuracy of apparatus and technique. The theoretical aspects of the phono-photographic camera and technique have been discussed, and it remains to explain the tests performed to prove the suppositions.

The first of the basic tests of apparatus and technique were conducted from Seashore Pitch Record 1A (Columbia No. A 7536) on the short strip plan of photography. This program was somewhat as follows:

1. A preliminary analysis was made of all possible errors which might enter into the pitch and duration-deriving process.

2. The first crucial test was to photograph the same tuning fork tone of the Seashore pitch record two times with exactly the same result. In the next tests the relation of the record to the drum (B, Fig. 1) was varied to eliminate the possibility of error due to the drum about which the film was clamped.

3. With the knowledge that the apparatus enlarges the wave

lengths without distortion from a phonograph record, the pitch and duration error in the phonograph record could be isolated, in the determination of its use in scientific studies of vocal expression.

4. The fundamental test of photographing the same tone twice in exactly the same way would also prove that none of the previously supposed errors were operative, any one of which could have destroyed an exact duplication of photography of the same tone.

5. In order to ascertain whether the pitch and duration error in the phonograph record was the result of any factors other than the driving motor, tests were made in the manner in which the recording of the Seashore Pitch Record was actually performed. These photographs were made on the apparatus used by *Simon.*(10) Six photographs were made of the tenth tone (459 d.v.). Three separate films were used, the record being moved so that its relationship to the drum was different for each of the three films. The tone was photographed twice on each film, the second photograph being directly on top of the first. In each case the pictures coincided throughout exactly. In Fig. 2, B, there is an interesting place, marked by an arrow, where the second exposure of the tone began on the first. This place is perceivable by the eye, because of the slight widening of the line where the two exposures were made. Furthermore, when the three films were superimposed, the coincidence was none the less marked. This same test of six photographs was repeated four times at various places on the record.

It is obvious that if the apparatus were inaccurate, it would have caused a variation in the wave-lengths in the matching effect produced by the superposition of one set of waves on the other.

Isolation of phonograph recording error. A survey of instruments for pitch and duration studies of speech and song in the literature fails to reveal an instrument which could meet the requirement of taking two pictures of the same tone from a phonograph record without error and thus have the pictures

exactly alike. For this reason the isolation of error in the original recording of a phonograph record has not been performed, since an error might be introduced in transferring the wave-length from record to film by the apparatus.

Tones were photographed from various parts of the Seashore Pitch Record 1A, and were read for pitch in wave lengths. It so happened that a pitch of 459 d.v., sounded into a phonograph recorder at 78 r.p.m., and reproduced on a film with its speed equivalent to 2.549 cm. for .01 sec., would have a wave length of 5.55 mm. But .1 mm. was the finest unit in which wave-length may be accurately read (Cf. *Simon* [10]). Thus the readings would have to be made in terms of 5.5 mm. and 5.6 mm. If there were no error in the phonograph record, and the readings were made without error, they would give a definite pattern on a graph when read cumulatively. Fig. 4, A, shows this situation.

Compare this pattern with the following graphs in Fig. 4, waves photographed from tones in various parts of the record. The graphs by inspection show an increasing tendency toward error from B to K. It so happens that B, C, D, and E are graphs of tones taken at the beginning of the Seashore Pitch Record, F, G, and H at the middle and I, J, and K at the end. It would therefore seem that the error of recording increased as the center was approached.

In order to eliminate all factors in the recording of the Seashore Pitch Record other than the motor's constancy and the friction of the recording-needle, a tuning fork of 435 d.v. was sounded into a resonator when the fork was tightly clamped and also when held in the hand. These tones were then photographed on a film and wound around the tonoscope. The same set-up of single light, phonelescope and lens was utilized as in the case of the single revolutions, the base line being made when the light was reflected from the phonelescope mirror at rest, and then the vibrating light produced by the tuning fork sound waves photographed over it.

Four films were taken in this fashion, two with the tuning fork clamped and two unclamped. A pitch of 435 d.v. photographed

on a film traveling at a constant rate of 242.5 cm. per second has a wave length of 5.57 mm. Fig. 5, A, shows the pattern which would result on the graphs if the film traveled at a perfectly constant rate, with readings made without errror.

The plan of reading followed was that of fitting all measurements, if possible, into a 5.5 mm. or 5.6 mm. scheme. Its justification lies in the fact that if a reading did not fit into the scheme

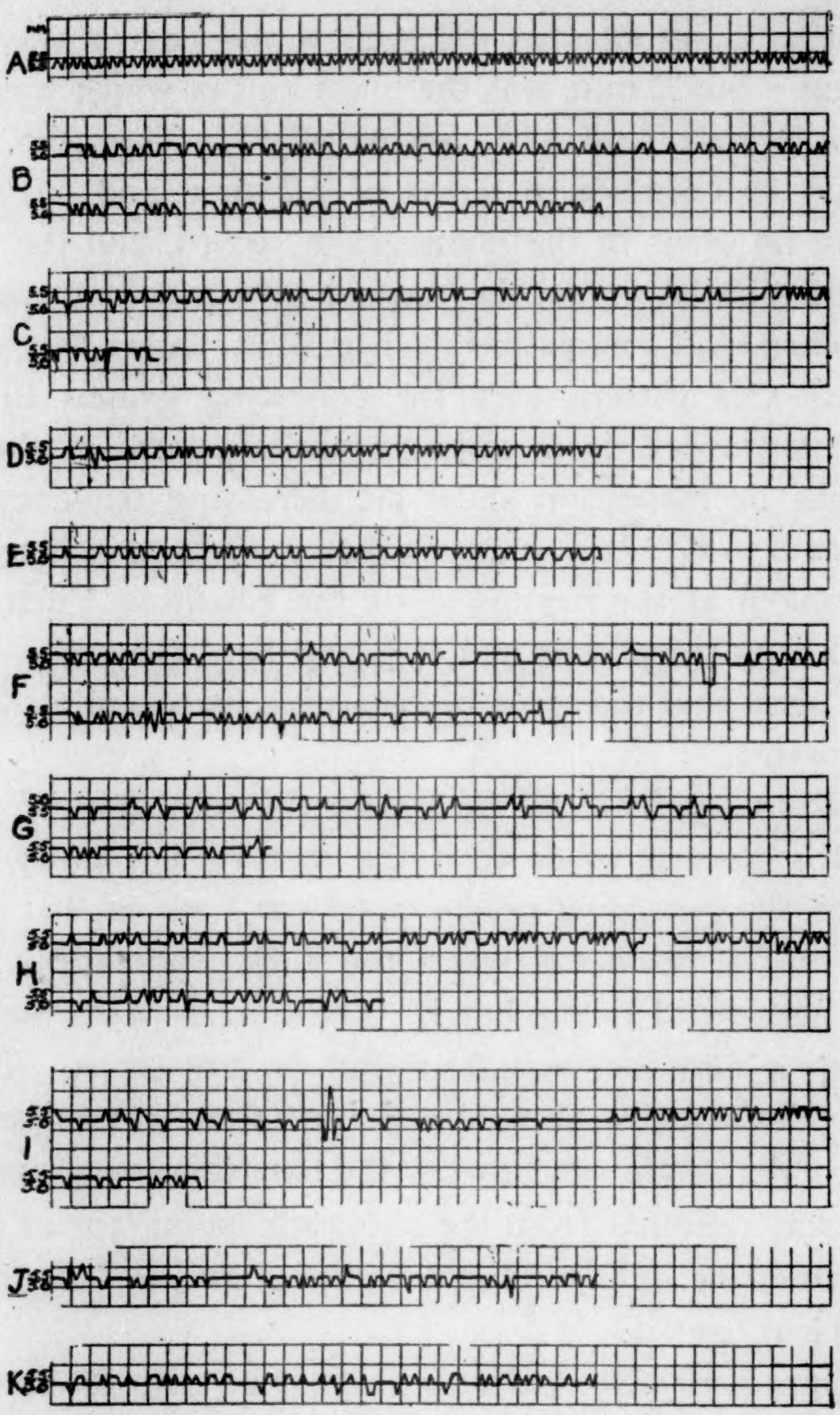


Fig. 4

it was a positive error in recording and not one resulting from reading.

None of the readings definitely follow the ideal patterns in Fig. 4, A, and Fig. 5, A, but it may be regarded as a very satisfactory degree of constancy of movement if the readings occur as either 5.5 or 5.6 for present comparative purposes. If all the readings are one of these two, it means that the error in recording is less than the error in reading (plus or minus

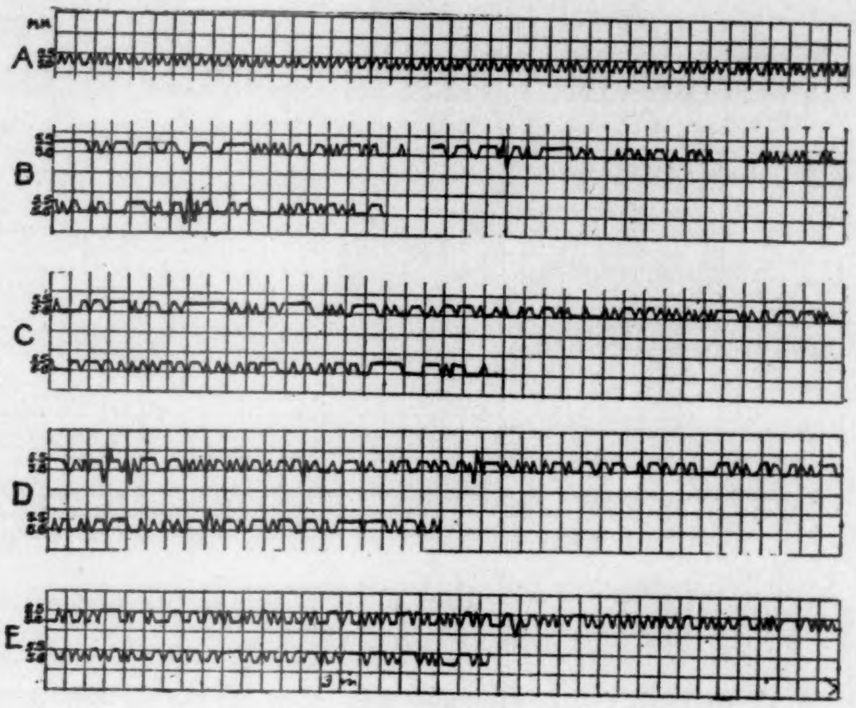


Fig. 5

.05 mm.). The graphs make it evident that, with the exception of the record closest to the center, the phonograph record is sufficiently accurate for studies in vocal art.

Tests of photography with long lengths of film. Having thus treated the basic tests of accuracy of the apparatus and the recording of phonograph records, the next step was concerned with trying out the added possibility of error when the apparatus is used for the longer lengths of film. Would the tension offered the drum upon which the film is winding affect its regularity enough to make erroneous pitch readings?

It will be recalled that the success of the apparatus depends upon a degree of constancy of film movement during the interval

in which the known tone, 100 d.v., completes its cycle of movements known as one complete vibration. In Fig. 2, A, this would be from one of its critical points of intersection to the next. Should this film vary markedly in speed during this .01 sec., the sound waves grouped in these limits to be counted as occurring in that given time unit, would be more or less than is actually the case. The variation of the speed at which the film travels should be very gradual, and must be less than the error involved

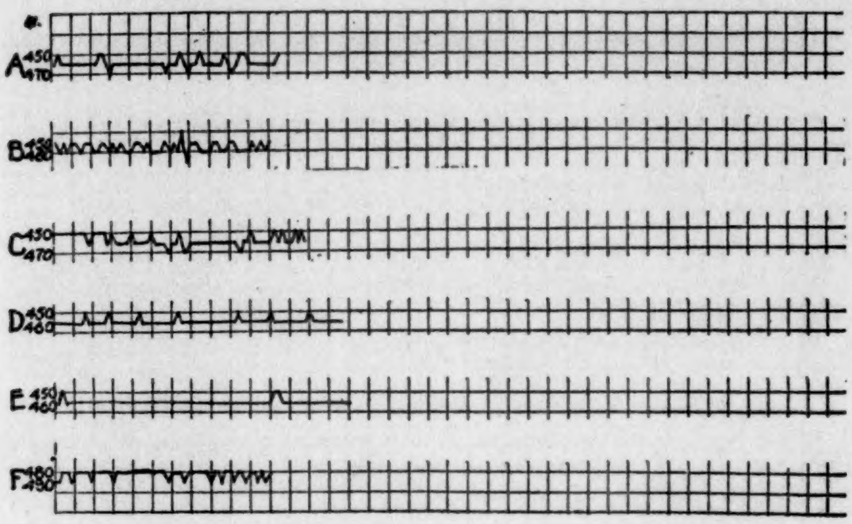


Fig. 6

in reading the number of vibrations in a given time unit. This error is plus or minus .05 mm., for wave length readings in terms of .1 mm., plus or minus five d.v. in reading by waves grouped within the .01 sec. unit in terms of .1 wave, and plus or minus 2½ d.v. for .02 sec. in terms of .1 wave.

Fig. 6, A, is the tenth tone of the Seashore pitch record 1, A, photographed with the film driven from the film box and wound around the drum. Each reading represents .01 sec. B in Fig. 6 is the sixtieth tone, and C the ninety-eighth. D is the sixth, E the seventh. F is the twenty-second tone, which is not a standard tone, but 23 vibrations above.

Another test of the regular rate with which the film winds up on the apparatus was made by the doubling back of a film on itself. The 435 d.v. sine wave showed a very slight creep which would be expected by a slowly changing rate of passage.

The graphs speak for themselves. If there were any irregularity due to the tension of the film passing the rollers it did not become evidenced in the final reading.

Types of Technique: (2) With Phonoptical Devices

A. *Seashore tonoscope.* In the determination of certain pitch factors in artistic singing, the Seashore tonoscope (7) was found to be both accurate and immediate. The tonoscope operates on the principle of stroboscopic vision. A Koenig manometric flame capsule has been previously used, the vibrations of the voice in striking a diaphragm causing a raising and a lowering of a tiny acetylene gas flame. Any surface illuminated by the vibrating light actually would present its stimuli in flashes as many times per second as the vibrations of the voice singing into the manometric capsule. The eye sees the surface continuously due to retinal lag. However, if a revolving drum with any type of delineations, such as holes punched in the drum, should have the same number of holes pass a given point as there were flashes of light, these would be seen as stationary dots by the eye. The Seashore tonoscope has rows of holes in steps of one vibration from 110 to 219. The 110 row would show a pitch of 220 and 440. A pitch of 220 d.v. would be observed as having twice as many dots as a pitch of 110. 440 dv. would have four times as many.

The inconveniences resulting from a device using acetylene prompted the supplanting of the manometric capsule by a phonelescope. An arc light is used, and the phonelescope is placed five feet from the tonoscope. There is a swing of the beam from the phonelescope horizontally across the entire face of the tonoscope on the medium loud tones. An Audiophone [1] is used to amplify the tone from the phonograph microphone transmitter to accomplish this result from phonograph records. The "hand speech transmitter" of the Audiophone is utilized for readings directly from the voice. For soft tones a concen-

[1] An Audiophone is a commercial device manufactured by The Bristol Co., Waterbury, Connecticut.

tration of the beam of light on the tonoscope is possible by adjustments on the phonelescope. The loud speaker of the Audiophone presents to the ear what is seen by the eye on the tonoscope. This is of especial value in the case of phonograph records where the speed is reduced.

Technique of reading. Not only the row of dots synchronizing with the pitch which is being read may be seen on the tonoscope, for the rows immediately to the right and to the left appear. The correct pitch may be singled out because it stands still, while those to the right move upwards with the rate of movement increasing with the distance from the true pitch. Likewise the rows of dots to the left move downwards. This means that the general position of the right reading may be found with attention to the pattern, rather than to a single row of dots. The middle row of the pattern which represents the pitch being sung may then be observed more closely. In studying rapid pitch glides on the tonoscope, this pattern serves alone to indicate pitch movement.

When there is a special recurrent pitch fluctuation to be read on the tonoscope, a different technique is of assistance. For example, in artistic singing, as was shown in Fig. 3, the pitch is constantly undergoing a recurrent change about a general level, known as the pitch vibrato.

The middle or mean pitch of this oscillation distinguishes itself on the tonoscope by the fact that it has a fairly even pendular motion. This occurs at the same rhythm as the pulsation heard from the loud speaker. In the vibrato the rate of pitch change is greatest at the mean pitch, slowing up as the limits are approached. It will be recalled also that the rows to the right and left of the correct pitch are seen, the former moving up and the latter down. Therefore, when the pitch in moving from one extreme to the other reaches its lowest point, the mean pitch row is moving upwards and on reaching its highest point the mean pitch row appears to move downwards. No other row of dots would present this even rocking because the distances from the extremes are not equal.

The lowest pitch may be picked out because the row corresponding to it on the tonoscope seems to be moving downward most of the time since the tone is nearly always above it, but it comes to a standstill with the same regularity as the pulsations heard from the loud speaker. The row representing the pitch just below the real limit has almost the same appearance in that it is moving downward, but it never completely stands still. When reading the lower extreme, one must make sure that the dots stop moving for an instant.

The principle of reading the highest pitch is just the reverse of this in the sense that the dots are moving upward most of the time. To be certain that the limit is actual, a momentary halt must again be observed.

Thus the three points which give the mean pitch and the extent of the vibrato each have characteristic effects. The mean pitch is represented by the only row of dots regularly moving up and down. The extreme points have the advantage of the slowest rate of pitch change so that while the limits move upward or downward most of the time, the halting of the movement of the dots is of sufficient duration to be observed.

The detailed procedure in reading the pitch vibrato on the tonoscope from phonograph records at one-third normal speed would be: (1) Pick out the mean pitch, noting whether it shifts and how much during the progression of the tone. Experience has shown that a record of the mean pitch for every other audible pulsation is sufficient. (2) Ascertain the upper pitch limit, watching for changes in every other pulsation. (3) Find the lower limit proceeding in similar fashion.

The upper and lower limits act as a check against each other since they should both be the same number of vibrations from the mean pitch. Two observers reading the same tone may thus insure accuracy, the one confining his readings to the upper, the other to the lower limit.

Certain precautions must be taken in work on the tonoscope from phonograph records at slow speed. The phonograph was driven by the synchronous motor of the tonoscope, a belt passing

about a pulley on the axle of the tonoscope and around the phonograph turn table. Slippage was reduced to a minimum by sufficient tension and friction. The fact that the mechanical features of this arrangement did not materially alter results was proven by a comparison of tones in Fig. 9 read from photography from phonograph records. The extent of the oscillation was slightly greater from tonoscope readings in every case checked. The explanation of this will follow later.

Slowing the record down calls for computations in order to have all pitch readings in terms of the fundamental. Since pitches on the tonoscope at such a slow rate in most cases were higher partials of the tone sung, the mean pitch and the extent have to be multiplied by a constant for each partial. It is only when the distance between the dots seen corresponds to the actual distance of the holes on the drum that the tonoscope records a pitch range of 110 to 219. If the dots seen are twice the actual distance, the pitch is half, and if half as far, the pitch is double. It was found that since the tonoscope shows overtones as well as fundamentals, nearly all the tones could be read so that the distance of the dots seen would correspond to the distance on the drum. For example, a tone with a pitch of 150 d.v. on a phonograph record when slowed down to one-third the rate of recording would have its fundamental tone reduced to 50 d.v., (150/3) the second partial, 100, (300/3) the third partial, 150, the fourth, 200, the fifth, 250, etc. The third and fourth partials would both appear on the tonoscope. If the fourth were read, since the phonograph record revolves only 29 r.p.m. instead of 78, 200 must be multiplied by three to get the actual mean pitch of the fourth partial at the time of making the record. To reduce this to terms of the fundamental, 600 must be divided by four. The operation is a matter of $200 \times 3/4$. If the fourth partial shifted to 220 d.v., the true value of the fundamental would be $200 \times 3/4$, or 165. Thus an extent of pitch oscillation of twenty vibrations in this example, as read on the tonoscope, would actually be fifteen vibrations. (150 to 165.)

The tonoscope method of reading these pitch factors is superior

to the phono-photographic method in the cases of phonograph records where orchestral accompaniment entered into the wave form. In many instances in the photographed wave the reading of a wave-length is impossible due to this orchestral interference. On the tonoscope, the pitch readings of both the orchestra and the voice are clearly differentiated.

The extent in terms of pitch has been referred to as the range of pitches covered during one oscillation of the vibrato. Perusal of Figs. 7, A to D, and 8, A to D, shows that this extent varies from one-quarter to over a half tone. This is quite at variance with *Schoen's* (6) extent as read on the Seashore tonoscope. Schoen's results are stated as: "in terms of vibrations the extent of the vibrato is about the same throughout the entire range of the voice, being 10, 11, and 12 d.v. for the lowest, middle and highest ranges, respectively, or 0.25, 0.15, 0.09 in terms of part of a whole tone." The results of the present research show that the extent in terms of part of a tone is far more constant throughout the range of the voice than in terms of vibrations. Schoen states that the phonograph for his experiments was slowed down to six revolutions per minute, which means 1/13 normal rate. At a pitch of 520 the fundamental, when the record was played at 6 r.p.m., would be only 40 d.v. The third partial would be reduced to 120, the fourth to 160, and the fifth to 200. Each of these three would show on the tonoscope with the spacing of the dots seen corresponding to the spacing of the holes. Supposing that the fourth partial were read in which the actual extent—at 78 r.p.m.—was thirty-nine vibrations, the extent as read on the tonoscope would be twelve vibrations ($39 \times 4/13$). It is possible that this would explain the difference in result, in that Schoen failed to compute the number of the partial which he was reading on the tonoscope.

B. *Phono-projectoscope.* This device was built in the laboratory separately from this enterprise, but it was used for the beginning stages of several problems before actual photography. Instead of the phonelescope throwing a beam across the face of the tonoscope as was just described, the light ray is projected

against a revolving four-sided mirror mounted on a phonograph. The sound waves are in this way projected on a screen and may thus be studied as they will appear on the photograph.

Types of Technique: (3) *With Ear Analysis of Phonograph Records*

The artistic singer does not always follow a given score of a song, and this is true especially in the instance of folk songs. It is thus desirable to listen to a record and make a conventional notation of it as the first step in its study.

Intensity changes from tone to tone and during the progression of a single tone may be roughly ascertained by the ear. A subjective value for soft tones, medium tones, and loud tones will function for a rough survey.

The actual speech sounds used are quite evident to the ear, and thus numerous problems in the effect of various qualities of tones will be possible of solution.

By listening to the phonograph record when slowed down, nearly all the factors of duration involved may be recorded by what will be referred to as the "tapping method." *Kwalwasser* (3) introduced such a procedure listening to the slowed pulsation of the vibrato, and tapping synchronously with them on a paper placed on a phonograph table revolving once a second.

In the present instance the tapping was done on the same table upon which the playing phonograph record was placed. The pulsations should be tapped out twice in order that the taps in coinciding may verify. An error of more than .01 sec. should result in further repetitions. The duration of an entire tone, or that of the separate vowels, voiced consonants, and voiceless consonants may be so recorded.

The paper discs upon which the tapping was done were placed on top of a still larger disc marked off into 77 equal divisions, representing .01 sec. of time of original recording, at 78 r.p.m. The time from one mark to the next was thus measured in terms of .01 sec.

II. Sample Results from Different Methods Used

Figs. 7, 8, and 9 are nine plates of graphs, the first eight of which are a new type of musical notation suited primarily to representing graphically the objective pitch and duration variations in a song as it is actually sung. An attempt to use the conventional musical staff proved futile because of the fact that the vertical distance between horizontal lines on the scale has a value in some cases of a whole tone and in others a half tone, while notes with sharps or flats would find awkward display.

These difficulties were met by assigning the distance from one horizontal line upward to the next a value of one-half tone regardless of the pitch. In terms of vibrations, of course, the value of a half-tone increases with the rise in pitch. For instance, in Fig. 7, A, the value of half steps beginning at the bottom are roughly 9, 9, 10, 10, 11, 12, 12, 13, 14, 14, 15, 16, 17, 18, 20, 20, 22, 23, vibrations each.[1]

The major triad (do-mi-sol) is on the graph to assist the reader in adjusting to the new type of staff. The distance represented by one second of passage of time is blocked off on the lowest part of each graph. Musical notes are placed with their nearest correct time values so that the left part of the note is at the point as far as time is concerned where the first sound in each syllable begins. It is located on the theoretical pitch in each case.

The numbers placed directly under each syllable are in terms of hundredths of a standard quarter note. This standard was determined in these cases by averaging the seven most objectively equal measures, in terms of .01 sec., and dividing by four. For Welles, the standard quarter note had a duration of 102.75, while for McCormack it was 83.9. These figures are also an index to the tempo used. To illustrate, in the first graph in Fig. 7, " wel " is a dotted quarter note which theoretically should have

[1] The graphs are all presented with a standard width whenever a song is transcribed as a whole. (See Figs. 7 and 8.) Whenever short sections are used (Figs. 9 and 10), only the width occupied during those sections is used. In a complete song notation the reader is thus able to keep the relations of the tones to each other in mind without special reference to the letters at the left of the graphs for each instance.

a value of 150. Actually it has 153, and so these numbers show artistic deviations in duration.

Sample of Results from Direct Phono-Photography

Fig. 7, A to D, contains 12 graphs of pitch and duration notation of the entire first verse of "Annie Laurie" as sung by Lowell Welles, and photographed directly in the laboratory. The readings of pitch and duration were made in terms of .02 sec. units. The smoothing effect of readings of this type was discussed above. It is possible that the range in terms of absolute pitch is slightly lopped off at the upper and lower extremes.

Results from Phonograph Record with Seashore Tonoscope, Ear Analysis, and Slow Speed Phono-Photography

Fig. 8, A to D, shows eleven graphs of the same song as sung by McCormack. The time values are, with film traveling at a slow rate, taken from the phonograph record sound photography, the rate of oscillation of the vibrato determined by the tapping method described in foregoing pages, and the pitch factors read at one-third normal speed of the phonograph record on the Seashore tonoscope. The extent of the pitch oscillation is probably more accurately derived from readings on the Seashore tonoscope. This is due to the fact that the scale on the tonoscope is graduated in steps of the one vibration, and any error was reduced because a partial was being read and had to be translated in terms of the fundamental (see foregoing pages). Reading the waves grouped in .02 sec. must be accomplished in steps of five vibrations over and above the fact that waves so grouped have their pitch averaged. The disadvantages of this method lie in that the more detailed pitch fluctuations in the approach and recession of a tone appear too rapidly even at the slow speed of the phonograph record to be caught by the eye on the tonoscope.

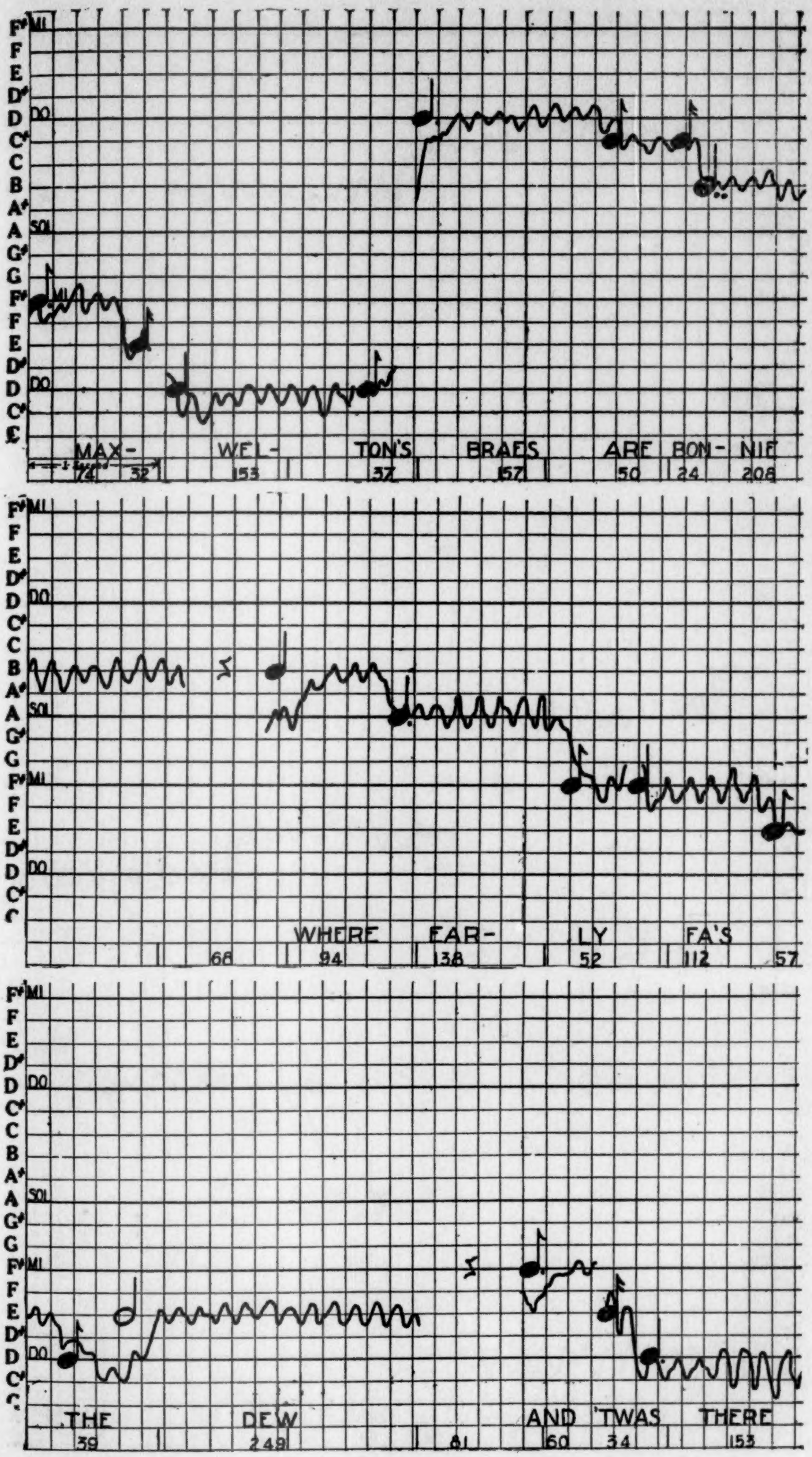


Fig. 7, A (Welles)

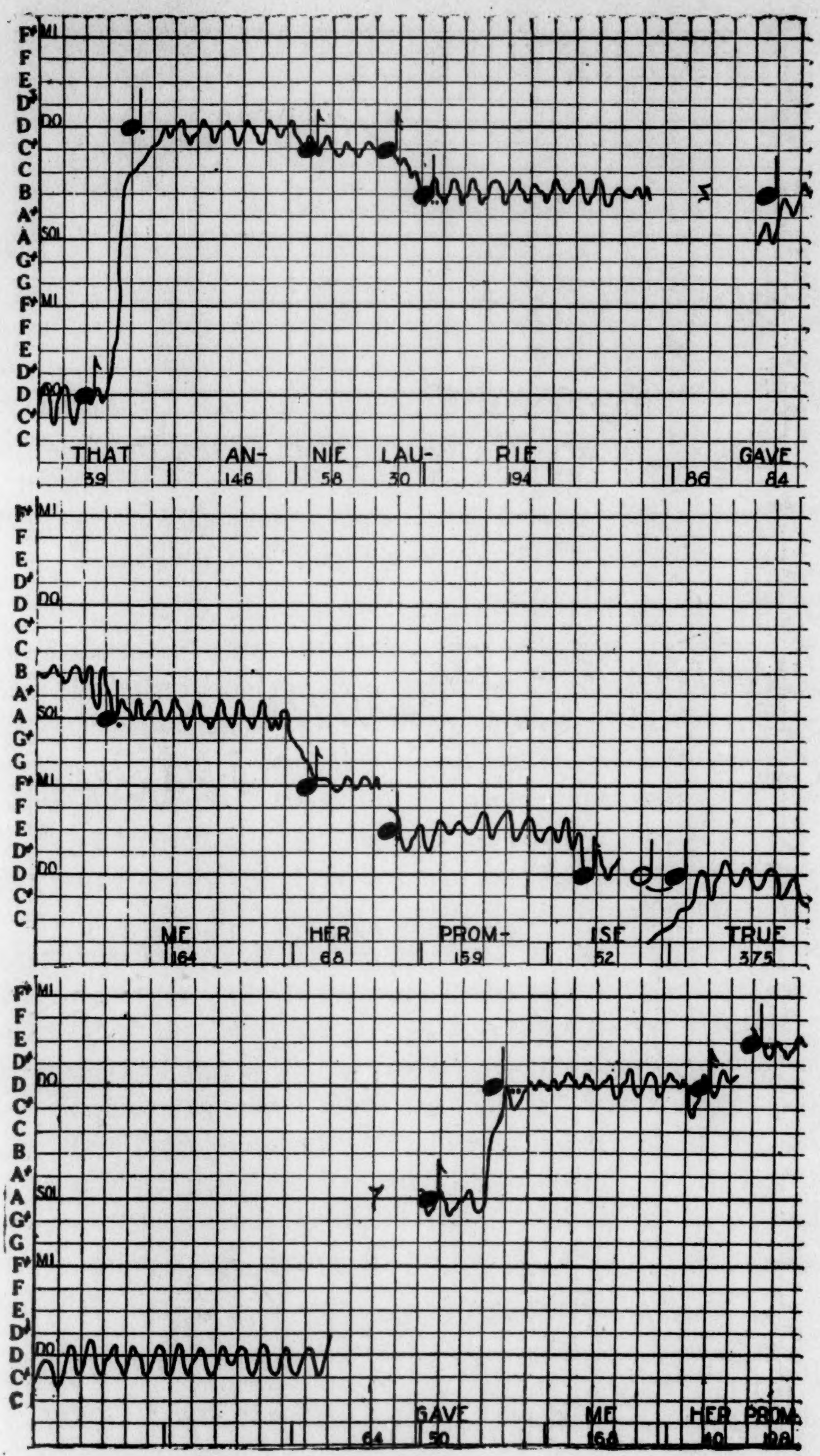

MI
DO
SOL
MI
DO
THAT 59
AN- 146
NIE 58
LAU- 30
RIE 194
86
GAVE 84
ME 164
HER 68
PROM- 159
ISE 52
TRUE 375
64
GAVE 50
ME 168
HER 40
PROM- 198

Fig. 7, B

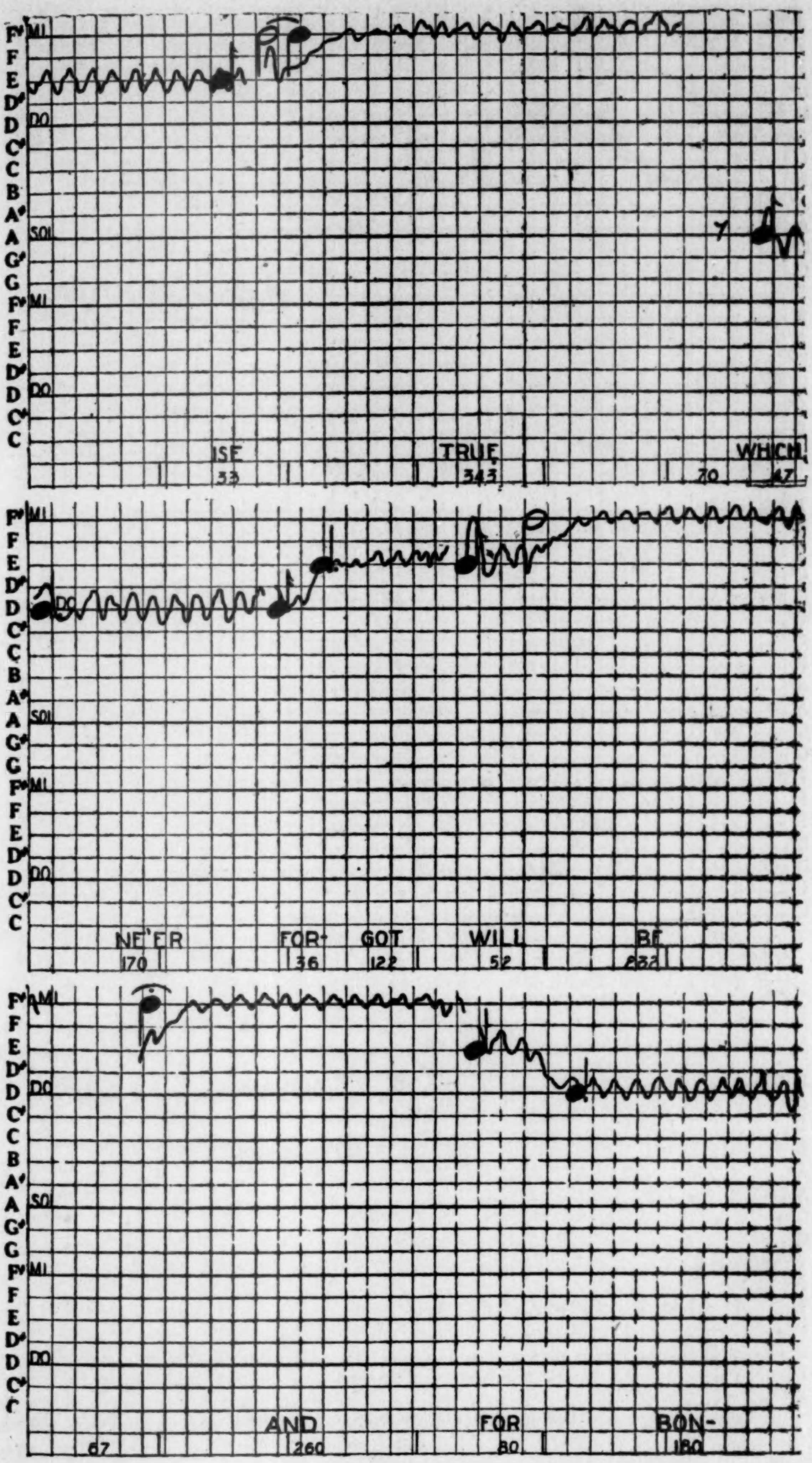

MI
DO
SOL
ISE
33
TRUE
343
WHICH
70
47
NE'ER
170
FOR-
36
GOT
122
WILL
52
BE
232
67
AND
260
FOR
80
BON-
180

Fig. 7, C

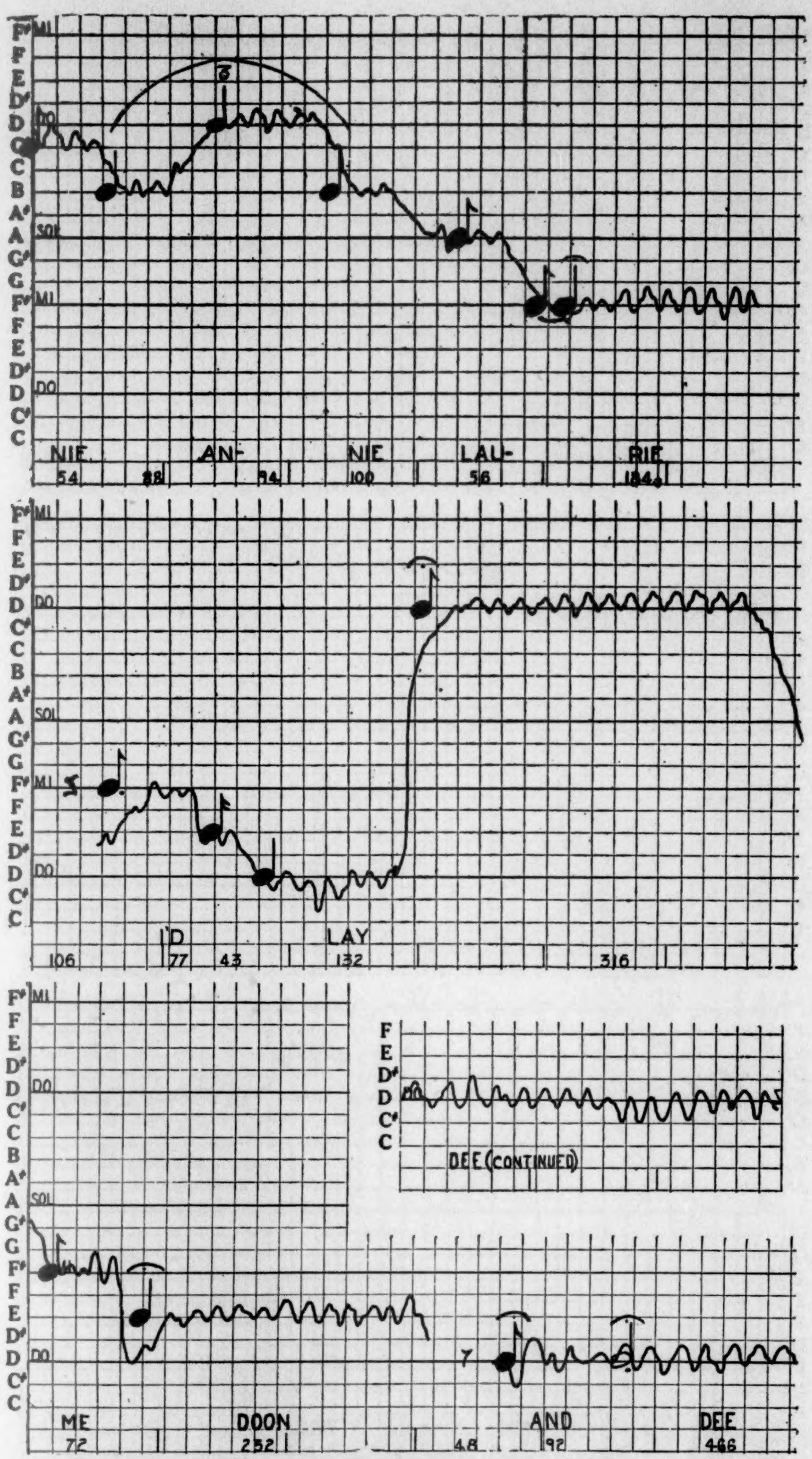

F♯ F E D♯ D C♯ C B A♯ A G♯ G F♯ F E D♯ D C♯ C
MI
DO
SOL
NIE
AN-
NIE
LAU-
RIE
54
88
94
100
56
184
D
LAY
106
77
43
132
316
DEE (CONTINUED)
ME
DOON
AND
DEE
72
252
48
92
466

Fig. 7, D

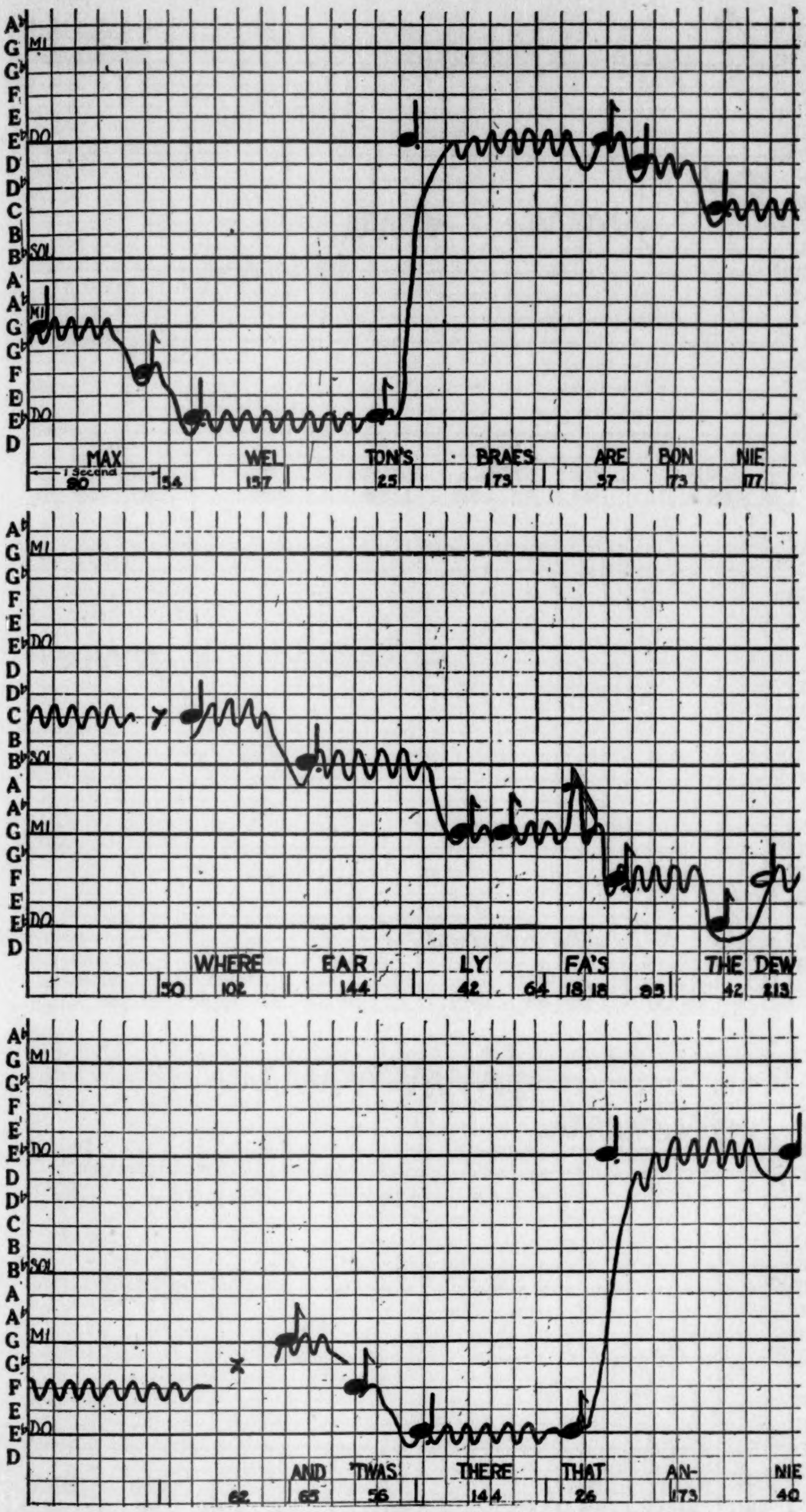
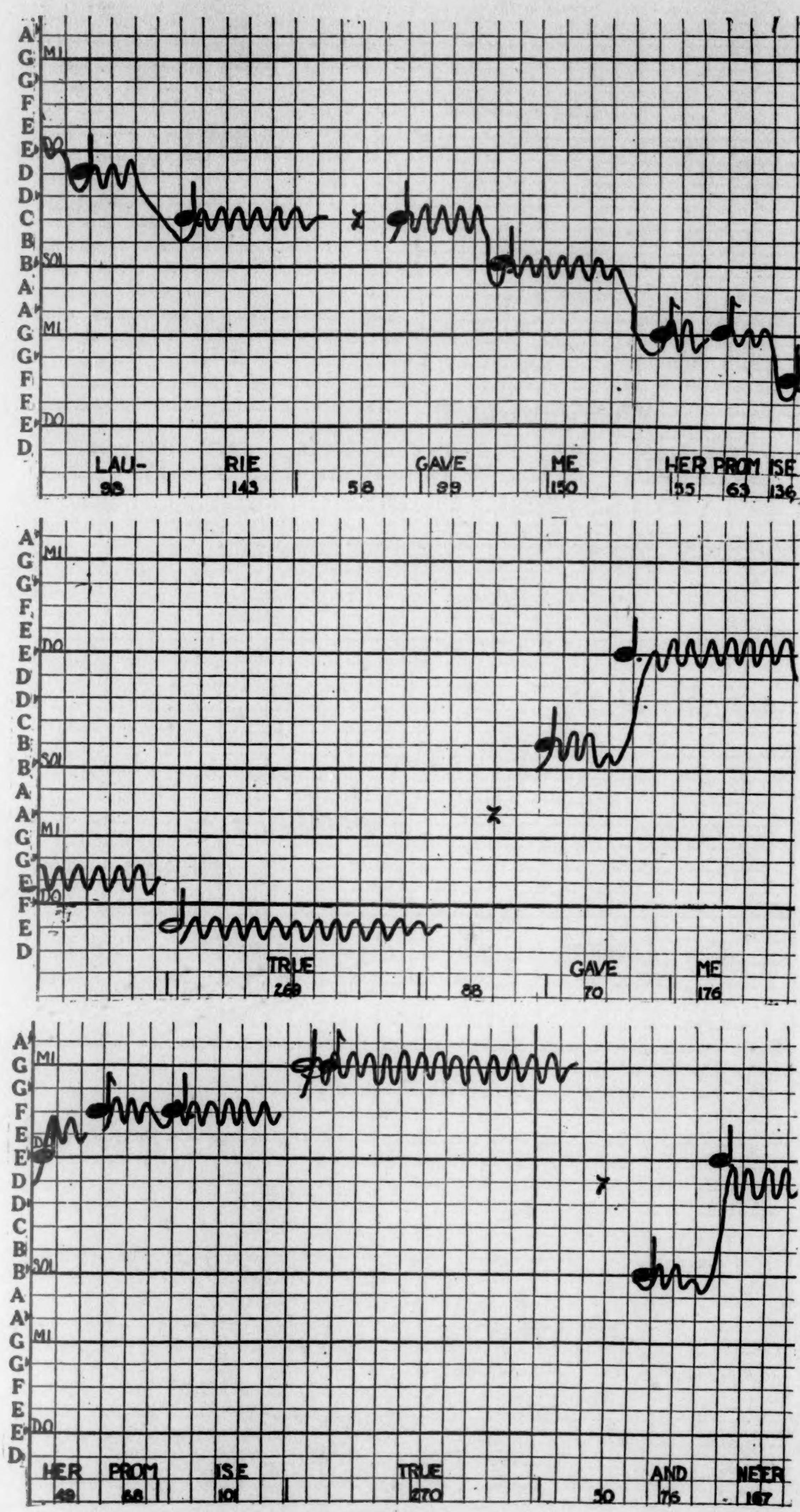
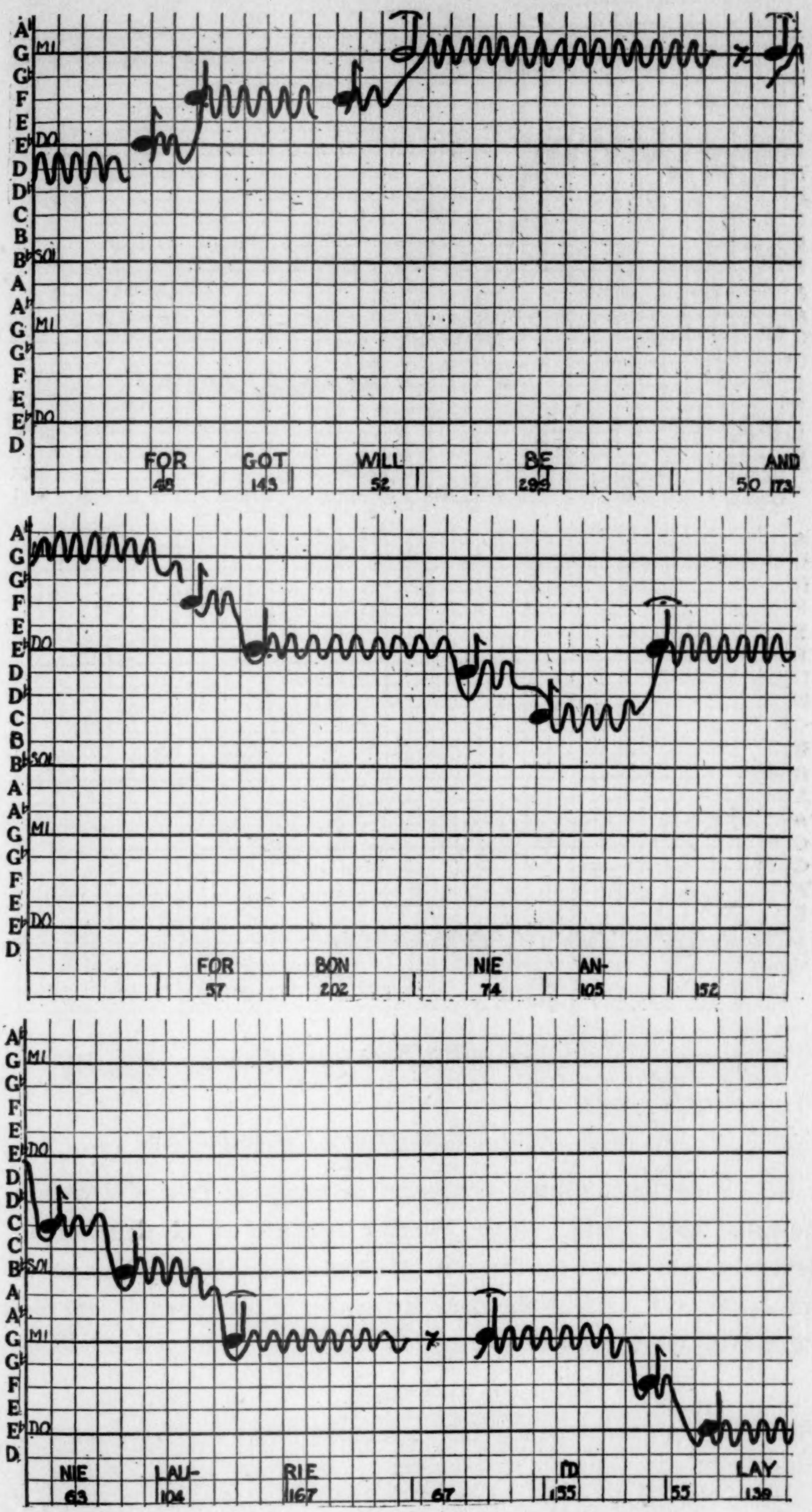


Fig. 8, A (McCormack)



LAU- RIE GAVE ME HER PROM ISE
93 143 58 89 150 55 63 136
TRUE GAVE ME
269 88 70 176
HER PROM ISE TRUE AND NE'ER
49 68 101 270 50 76 167

Fig. 8, B



FOR
48
GOT
143
WILL
52
BE
50
AND
173
FOR
57
BON
202
NIE
74
AN-
105
152
NIE
63
LAU-
104
RIE
167
67
I'D
155
55
LAY
139

Fig. 8, C

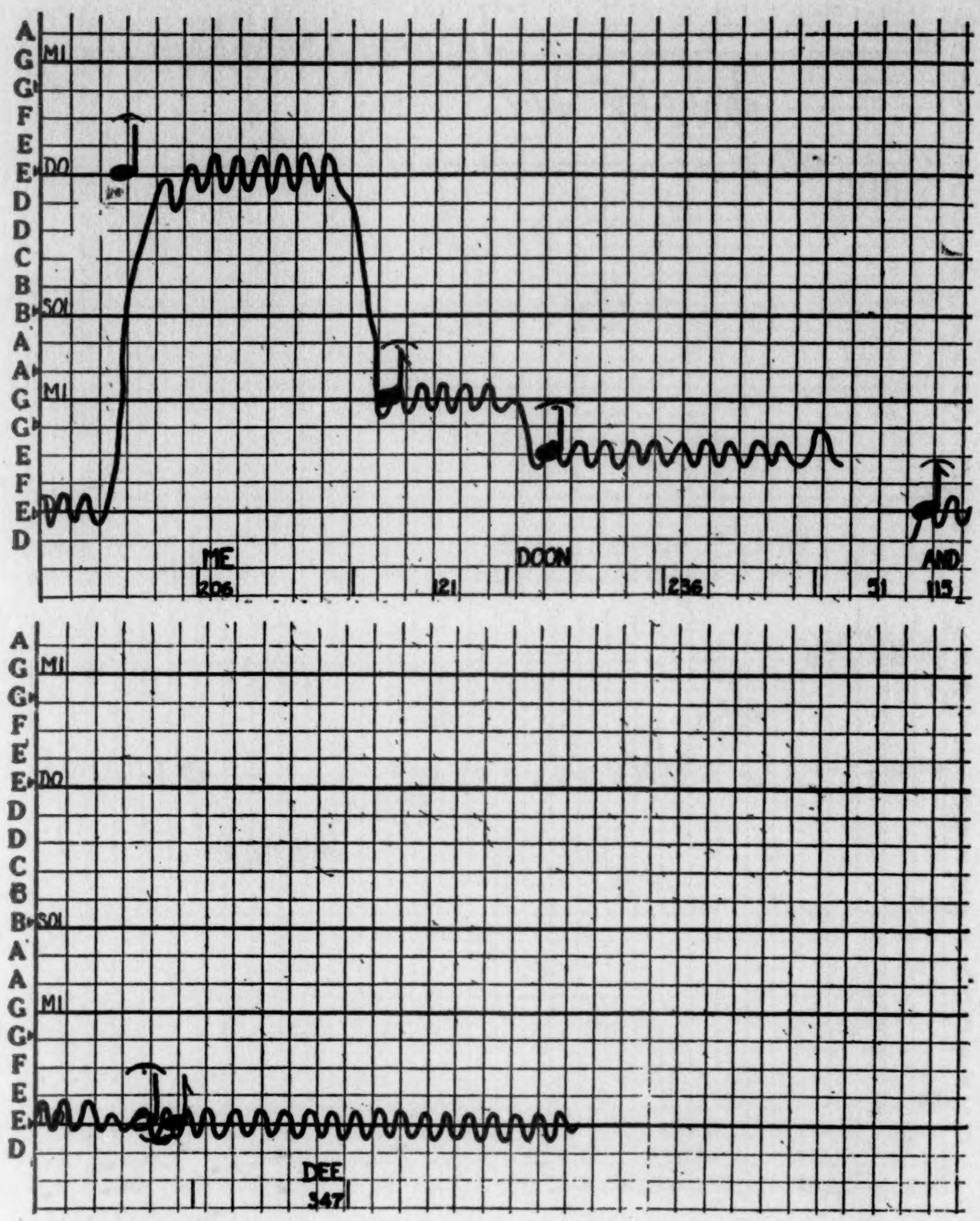


Fig. 8, D

Results from Phonograph Photography

Fig. 9 displays sample comparative tones of twelve artists on the same tone, " and," in the twelfth measure of "Annie Laurie," eleven of which are made from photographs taken by the phonograph method. As in the case of the direct photography method, the waves were read in groups of .02 sec. The tone of Welles

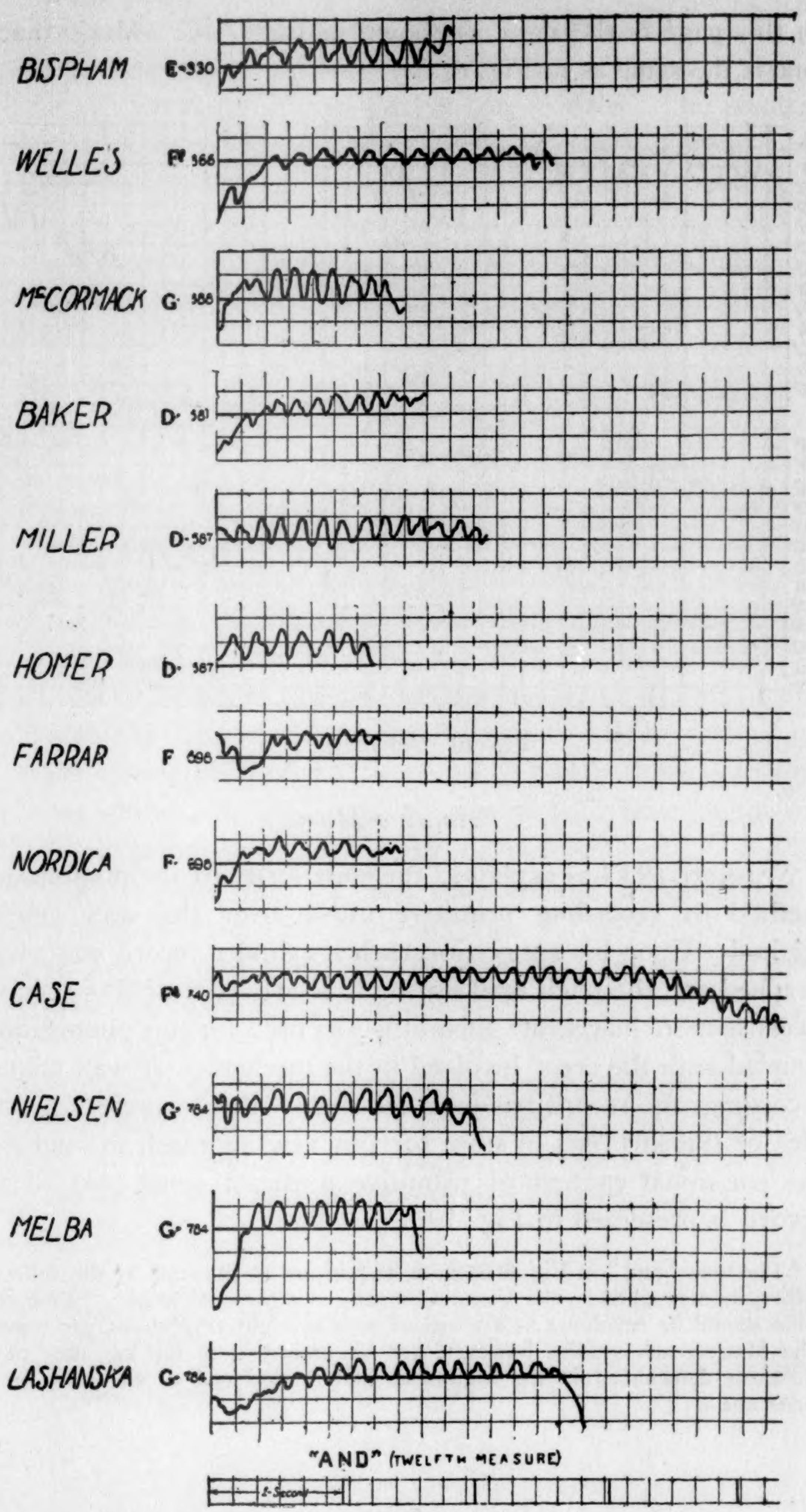

BISPHAM E-330
WELLES F♯ 366
McCORMACK G 388
BAKER D 581
MILLER D 587
HOMER D 587
FARRAR F 698
NORDICA F 698
CASE F♯ 740
NIELSEN G 784
MELBA G 784
LASHANSKA G 784
"AND" (TWELFTH MEASURE)

Fig. 9

on this page is the same as shown in Fig. 7, C. McCormack's tone is the same as in Fig. 8, C.[1]

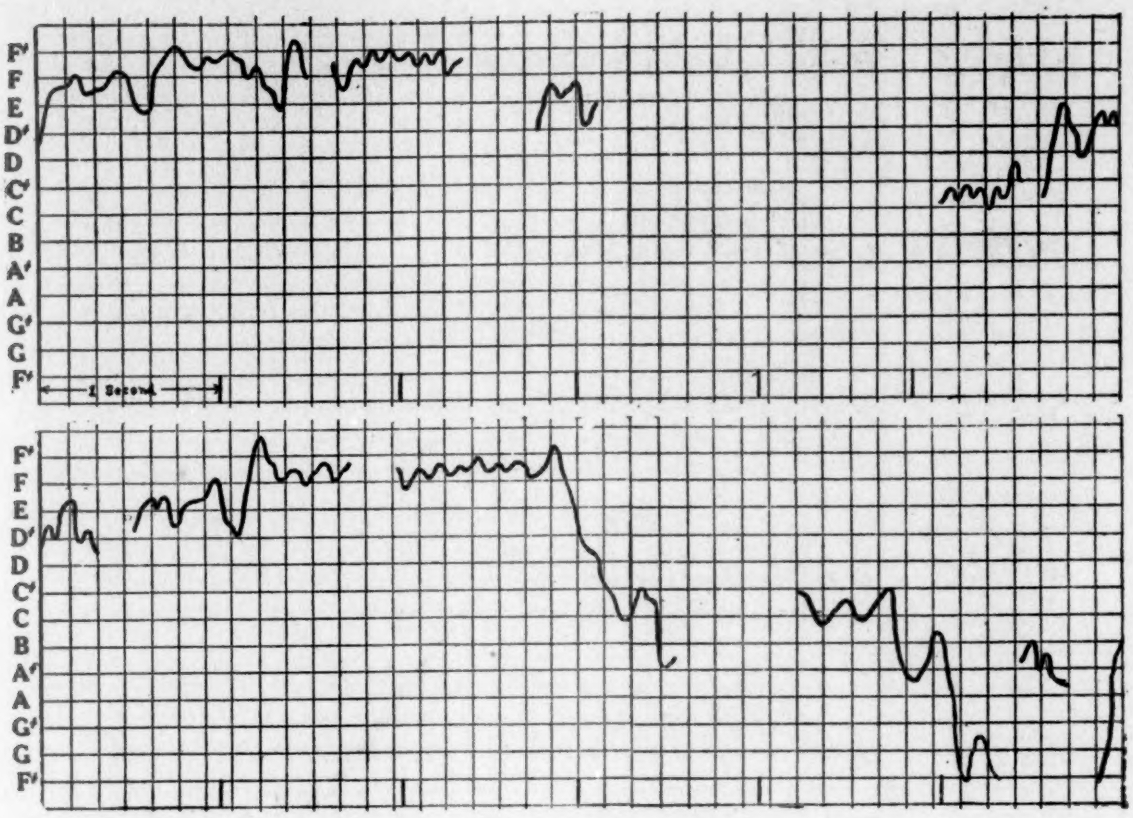


Fig. 10. An Indian solo

Primitive Music

Seashore (9) has explained the superiority of the photographic method of recording primitive music over the wax cylinder method. Upon his suggestion such a cylinder record was photographed and the pitch read during the early part of this research. Because more inaccurate apparatus was used for this photography, coupled with the error involved in the mechanics of wax cylinder recording, the record has been set aside. But to present a crude idea of the surprises in store for this new approach to studies of the emotional content of primitive music, a small part of this record is presented in Fig. 10.

[1] The tone "and" in Fig. 9 is given its position on the staff by the following information supplied by the Victor Company in a personal letter: "Your turntable should be revolving at a speed of seventy-eight revolutions per minute." The McCormack graphs, however, are set according to the key note of the orchestra determined in the beginning, middle, and end of the song on the tonoscope.

With the field type of phono-photographic camera, the vocal reactions of the primitive singer will be recorded in the same fashion as that of "Annie Laurie" by Welles. The results will then be similarly transcribed into scientific musical notation.

Analysis by the ear from these wax records is quite limited. It might be possible to ascertain some of the expressional factors in primitive music by the tonoscope method supplemented by ear analysis were it not for the fact that the number of times such a record may be played is too small for the requirements. The more intricate factors on the sound wave, such as tone approach and recession, would be omitted altogether.

Conclusions

1. A simple phono-photographic apparatus consisting of a drum, about which standard motion picture film winds after photographing the lights reflected from two phonelescopes, is recommended for use in all studies of pitch and duration when the record is made directly by the apparatus. This device is adaptable to later studies in intensity and timbre, to phonograph record photography, and to a record of bodily changes in singing and speaking. A field type of camera for phono-photographic studies in primitive music has been devised.

2. Tests made show (a) that the standard phonograph records pitch and duration sufficiently accurate for studies of emotional expression in music and speech, and (b) that records may be accurately transcribed photographically.

3. The optical method by use of the tonoscope is of great value for comparison and is adequate for researches of (a) general pitch factors from the voice directly, and (b) pitch from phonograph records, operated at low speed, supplemented by ear analysis for all duration and certain intensity and quality factors.

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THE VARIABILITY OF CONSECUTIVE WAVE-LENGTHS IN VOCAL AND INSTRUMENTAL SOUNDS

By Clarence Simon

I. Technique of measurements. Statement of methods: time-line method, wave length method; choice of methods: comparative accuracy, grouping of waves by the time-line method, comparative difficulty of the two methods; statement of units of measurement; choice of units: results of reading in various units, influence of the pitch of the sound in the choice of units; speed of the film; conclusions.

II. The fluctuation in pitch as measured in terms of variability in wave lengths for consecutive vibrations. Presentation of the data; the vibrato; the glide; graphic analysis; conclusions; graphs.

This investigation, conducted in the psychological laboratory of the State University of Iowa, is one of a series dealing with the problems of pitch fluctuation. In this study the object was twofold: first, to standardize a technique for recording and measuring sound waves; and second, to gather data concerning pitch fluctuations in vocal and instrumental sounds.

Part I. Technique of Measurements

Several methods of study have been used in this laboratory. *Schoen* (4) employed a visual reading of the tonoscope from phonograph records played at one-sixth the normal speed. *Merry* (2) used a tracing machine (5) with the addition of a spark device to mark intervals of .01 second on the smoked paper. *Herzberg* (1) and *Metfessel* (3) used a phonelescope and photographed the waves on a moving picture film.

Statement of Methods

By any graphic method used for recording the sound waves, there are two modes for determining the pitch of the sounds. The traditional one may be called the time-line method; the other the wave-length method.

Time-line method. The time-line method counts the number and fraction of vibrations occurring within a hundredth of a second. This mixed number is then multiplied by 100 to give the number of vibrations in a second. The fraction of a vibration occurring within the .01 second may be expressed with various denominators. In the past it has been written in terms of .1 of the length of the wave; but by using a measuring microscope, the intervals may be expressed just as easily in terms of .01 wave length, or even, if the wave be sufficiently long, of .005 of the length. The term "time-line method" is applied because the .01 second intervals are customarily marked off by a time-line, *i.e.,* alternating spaces of exposure and non-exposure on the film made by a beam of light interrupted every .01 second or by the superposition of tuning fork photogram.

Wave-length method. In the wave-length method the length of each wave is measured and these measurements are translated into pitch by a simple process of division. The rate at which the film passes the point of exposure is expressed in terms of millimeters per second. When this quantity is divided by the wave length in millimeters, the quotient represents the number of times such a wave would occur in a second, or the frequency.

The wave-length method requires that the film shall pass the point of exposure at a constant and known rate. After a series of tests concerned with both speed and accuracy of rotation, to be discussed later, the tonoscope (6) was accepted as a satisfactory means for fulfilling this requirement of the wave-length method, and the following technique for photographing was standardized.

The phonelescope was mounted in front of the tonoscope in the position usually occupied by the manometric capsule, and the light lever was focused on the drum. By means of a fixed mirror another beam of light was brought to the drum with its point of focus on a vertical line with that of the photographing light. This was done to provide an axis or base line for the wave curve.

The photographing was done in a dark-room, the only illumination coming from a photographer's safe light suspended above

the machine. Six to eight feet of film was wound on the drum of the tonoscope and secured by clips. After the tonoscope had been started and allowed to pass through its hunting period, the experimenter placed a small opaque screen in front of the film and switched on the photographing and axis lights. The screen was used rather than a switch in the light circuits because the lights build up to photographic intensity too slowly to expose properly the fore part of the film. A projection on the drum of the tonoscope touched the finger of the experimenter once each revolution of the drum, giving him the signals to raise and lower the screen, so that the entire film would be exposed, but no part of it double exposed. As each film was taken off the drum, it was numbered so that it might be identified later and also read in the direction in which it was photographed. This numbering was checked by comparison with the footage number placed on the film by the manufacturer.

At times, due to breath pressure against the diaphragm of the phonelescope, the mid-point of the wave fell away from the base line, so that the line approached either the peak or the trough of the wave. This might lead to inaccuracy in measuring, especially in those cases where the amplitude of the wave changes when the base line is out of its mid-position. The remedy for such a condition is to draw a new axis which actually bisects the amplitude of the wave at all points. The mid points of the waves can be determined by drawing tangents to both crests and troughs, joining the tangents on one side of the wave into a continuous line, and setting off points half way between the continuous line and the various tangents, one point for each wave. By joining these mid-points, a base line is drawn which actually bisects the wave at all points on the film.

After standardization of a technique for photographing, it was necessary to choose some method of measurement whereby these photographs might be interpreted. Measuring of the length of the waves with the naked eye was found to be too coarse, while a microscope vernier graduated to read in 1/200 mm. proved too delicate. A projection lantern was fitted with a special film

holder carrying a transparent millimeter scale; but the film shrinks on exposure to heat, the shrinkage amounting, in some instances, to 2 per cent. So it seemed advisable to return to the measuring microscope; this time, however, mounting it on a vernier graduated to read in units of .1 mm. After a series of tests, to be discussed later, this was accepted as satisfactory.

With this apparatus, wave-lengths were measured cumulatively for the distance allowed by the vernier. Because of the construction of the apparatus, certain precautions were observed to insure accurate readings. When the carriage was brought back to zero, for a new series of readings it was run as far as it would go and then turned up to the zero point from the left, or the direction in which the readings were made. Again, if the hair line were moved past the point of reference on the film, the microscope was turned back several millimeters beyond the point and adjusted from the original direction. To eliminate a possible error arising from a failure to set the instrument exactly at zero on the first reading, one other precaution was adopted, namely, using the last wave of the preceding series as the first of the following, and getting the two measurements of this wave to agree.

The measurements obtained in this way were converted into pitch by dividing the speed of the film, 2,425 mm. per second, by the wave length in millimeters; the quotient being the frequency. A work-table was prepared giving the frequency value for all wave-lengths encountered in the study.

Choice of Methods

Comparative accuracy. The prime factor in a comparative evaluation of the two methods must be that of accuracy, both mechanical and subjective. On the mechanical side, the wave-length method requires a constant speed of exposure of the film. After a series of tests, the tonoscope was found to be a satisfactory mechanism for this purpose. The first tests were simply a series of direct visual readings of the tonoscope as it recorded a sound of constant pitch. An electrically driven tuning fork with metal contacts was connected in circuit with a telephone

receiver made into a manometric capsule. Since the fork was pitched slightly above 102 d.v., no row of dots on the tonoscope stood still. The dots in the 102 row passing a given point were counted for one minute. The readings were taken in two series of five each, with five minutes elapsing between each two in a series and an hour between the two series. Table I gives the results of the test.

If the variation in rotation from one minute to another shown by the above table occurred when a sound of 128 d.v. was photographed and measured by the wave-length method, it would represent a mean variation from one minute to another of 1.3 d.v., or .00016 d.v. per wave, with other pitches correspondingly greater.

TABLE I. *Number of dots in the 102 d.v. line passing in one minute*

Series	1	2	3	4	5	m.	m.v.
1............	7.0	6.5	7.0	6.5	6.7	6.75	.20
2............	6.5	6.5	7.0	6.5	6.5	6.6	.16

But any two sections of the same film must be comparable also, which demands a constancy of rotation within one second, or one revolution of the tonoscope drum. A 100 d.v. fork was sounded into a Helmholtz resonator, a photograph was taken and the wave-lengths measured. Sixty-five waves were measured on this film, and three deviations from the mode were found; two of .1 mm. each, and one of .2 mm. The unit of measurement was .1 mm., hence well within the unit of measurement, while two of the three variations were equal to the unit of measurement, and only one exceeded it.

This same 102 d.v. fork was again photographed, but with the film exposed for two revolutions of the drum, thus placing two wave curves on the same film. Wave lengths were measured, using the intersections of the two curves as points of reference. Out of the seventy-five measurements made on this film, two varied from the mode, and these were .2 mm. smaller. The average deviation was, therefore, .0104 mm., s.d. .033 mm. In this case, also, both the average and the standard deviations were smaller than the unit of measurement.

As the mass of the drum is relatively great, the friction negligible and the drum well balanced and run on a constant pull, it is probable that the variation found in these two measurements is due mainly to the size of the unit of measurement, and not to any significant error in the drum. That is, the pitch of the fork was such that the wave length represented on the film could not be expressed exactly in terms of the unit of measurement. In this case the discrepancy between the actual and the imputed wave-length would increase cumulatively till it made some reading .1 mm. greater or less than the preceding one. And thus, because of the assumption that a tuning fork gives a constant wave-length, an apparent error in reading arises. But whatever the cause, the errors involved in reading a standard tone were only 6 per cent and 10 per cent of the unit of measurement; an error which tends to disappear within the unit.

To offset the problem of constancy of rotation which the wave-length method raises, the time-line method demands an accurate and sharp time-line. The points of reference for this line, however they may be made, must be definite. Both accuracy and sharpness of the line are mechanical features which approach the ideal as a limit.

In order to eliminate variation which might be due to inaccuracy in the time-line, this study has assumed for the present purpose, an ideal time-line, *i.e.,* the one second of film was divided into 100 units by actual measurement. An approach to this degree of precision has been gained in recent work by Metfessel in this laboratory by superposing a tuning fork wave upon the record wave and its base line.

Both methods may be used by measuring with the naked eye; nevertheless, to realize their utmost refinement, a measuring microscope must be used, and in the case of the wave length method in particular, no reliable results can be obtained without it. This brings the final test for accuracy with both methods to a question of the accuracy with which the readings can be made with a microscope. Since, with an apparatus of this type, any errors in the calibration of the instrument will be constant, the

chief concern is the subjective factor. Can an experimenter measure the same film repeatedly, either in wave-lengths or time blocks, with anything approaching consistency?

To answer this question the individual waves were selected as the quantities to be measured, and five readings made of a film taken from an untrained male voice, one reading on each of five different days. Several expedients were adopted to avoid the influence of memory: three of the measurements were made in the direction in which the film was photographed, or from wave 1 to wave 94, while two were made in the opposite direction—the two directions being alternated. Also, the measurements for the first ten waves and the last four were discarded before making the computations. The data are thus based on 80 waves, each with five measurements. Table II shows the result.

TABLE II. *Per cent of various deviations of various amounts*

Amount	D	S.D.
.00 mm.	5	5
.01–.02 mm.	31	0
.03–.04 mm.	33	38
.05–.06 mm.	21	54
.07–.08 mm.	9	2
.09–.10 mm.	0	1
.11–.12 mm.	1	0

D.—Variations for each of the five measurements for each wave from the mean of the five readings.
S.D.—Standard deviations of the readings for each wave.

This shows that only 1 per cent of these measurements deviated from the mean of the five readings by more than .1 mm., which was the unit of measurement, and the average of all deviations is .04 mm. The standard deviations show a similar uniformity.

But these measurements were made by one observer, and give no indication of the possible agreement or disagreement when two observers measure the same film. Accordingly, a film with an average wave-length of 17.9 mm. was measured independently by two observers. Of the 110 waves measured, 36 per cent showed a disagreement between the observers of .1 mm., while 1 per cent showed a discrepancy of .2 mm.; *i.e.,* the observers agreed exactly on 63 per cent of the readings and were within .1

mm. (the unit of measurement) for 99 per cent. The close agreement between the results from this test and the one by the single observer should be noted.

A possible source of error for both methods, quite aside from the mechanics of the situation, arises from the changes of contour in a wave taken from a voice tone with a variation of either the pitch or the quality of the tone. This change may be either an increase or a decrease in the number of peaks in the wave curve, or it may be that a different peak is lifted into prominence. Usually the change is slow and continuous, so that it may be followed without great difficulty. Nevertheless any system of counting peaks to determine where one wave-length ends and another begins may lead to inaccuracy when either the pitch or quality of the voice tone is changing. As a check to this error, it may be assumed that, for the ordinary voice tone, the fluctuations occurring with consecutive vibrations are not as large as a misinterpretation of the wave-length would represent them to be. For pitch studies, moreover, no attention is paid to the partials in the tone; the measurements are made from any selected point on the wave curve to the point where the wave begins to repeat itself.

So far, there is but little to choose between the two methods; in the ultimate refinement they are equally accurate, so far as mechanical and subjective details are concerned.

Grouping of waves by the time-line method. If the time interval used be .01 second, the time-line method will group into one reading as many waves as there are hundredths in the frequency. A tone of 200 d.v., for example, will be read in groups of two waves, while one of 400 d.v. will be read in groups of four. In other words, the single reading made by the time-line method is equivalent to the average pitch of the waves occurring within the time block. Not only does this smooth the resulting pitch readings, but the amount of smoothing will vary with the pitch. If this method be used to read a tone that rises through an octave, twice as many waves will be grouped at the end of the rise as at the beginning unless the period of the time block be changed.

The length of the individual waves may, of course, be approx-

imated by division of the time block, on the assumption that the passage of the film was constant for one time unit. But this method assigns the same pitch to all waves within the time block; a condition which this study has shown to be comparatively rare.

Comparative difficulty of the two methods. Another factor in the consideration of the two methods concerns the relative difficulties involved in apparatus and technique. The wave-length method demands that the film be exposed at a constant rate. So far as this study is concerned, this demand has been met by use of the tonoscope; but where exposures of more than one second are demanded, the problem becomes more serious. However, the tonoscope, or any other drum, may be equipped with the proper attachments to draw the film from a container, past the point of exposure, and into a receptacle. The amount of film exposed per second would then be determined either by the size of the drum or the speed at which it was run. This method, however, involves great danger of irregularity in the speed of the film.

There also remains the question of the speed and convenience with which the pitch readings may be obtained by the two methods. The time-line method may be either more rapid or slower than the wave-length method. If the readings are taken with the naked eye in terms of .1 wave-length, then the time-line method will give the final pitch readings in about 1/15 the time required for the wave-length method. If, however, the readings are made with the microscope, in terms of .05, .01 or .005 wave-length, then the time-line method requires much longer than the wave-length method.

Statement of Units of Measurement

There are two classes of units which should be considered: first, units of length, or the linear distance in terms of which the readings shall be expressed; and second, units of grouping, or the number of the quantities being measured (wave-lengths or time-blocks) which shall be combined into one expression of measurement. For the wave-length method, the unit of length may be .1, .5, or 1.0 mm.; while the unit of grouping may be one, two,

three, or even more wave-lengths. For the time-line method, the unit of length is somewhat different, for here the measurements are expressed in terms of the fraction of a wave-length which occurs in a given time block. Accordingly, for this latter method, the units of length may be .1, .05, .01, or, in some cases, .005 of the length of the wave. The unit of grouping may be one, two, three, or more time blocks. For both methods, the units of length and of grouping are independent; any unit of length may be selected as the basis of measurement without influencing the choice of a unit of grouping. For that reason, the two types of units will be considered separately in the following discussion.

Choice of Units

Results of reading in various units: A. Units of length. When the units of length are sufficiently fine, for example, .01 or .005 of the length of the wave for the time-line method, and .1 or .05 mm. for the wave-length method, the readings obtained by the two methods, are very similar. Four films were measured by the two methods, using these fine units, with the results shown in Table III.

TABLE III. *Average deviation between wave-length and time-line readings*

Film No.	Average pitch	Average deviation between the two methods
2	262 d.v.	.008 d.v.
A	152 d.v.	.0064 d.v.
26	408 d.v.	.0048 d.v.
54	122 d.v.	.0152 d.v.

This close agreement exists for two reasons: first, the readings by the wave-length method are not the vibration-by-vibration readings usually employed, but were obtained by averaging the individual measurements for the two or more waves occurring within the time blocks used as the basis of measurement by the time-line method. This averaging of the wave-length readings is necessary to secure comparability because of the grouping effect of the time-line method. The second cause for this agreement between the two methods is that the fraction of a wave-length

for which the measurements were made for the time-line method is very nearly equal in actual linear distance to the .1 mm. employed as the unit for the wave-length method. For example, film 2 has a mean wave-length of approximately 9 mm. This film was read in terms of .01 wave-length, which makes the actual linear distance taken as the unit .09 mm. Similarly, for film 54,

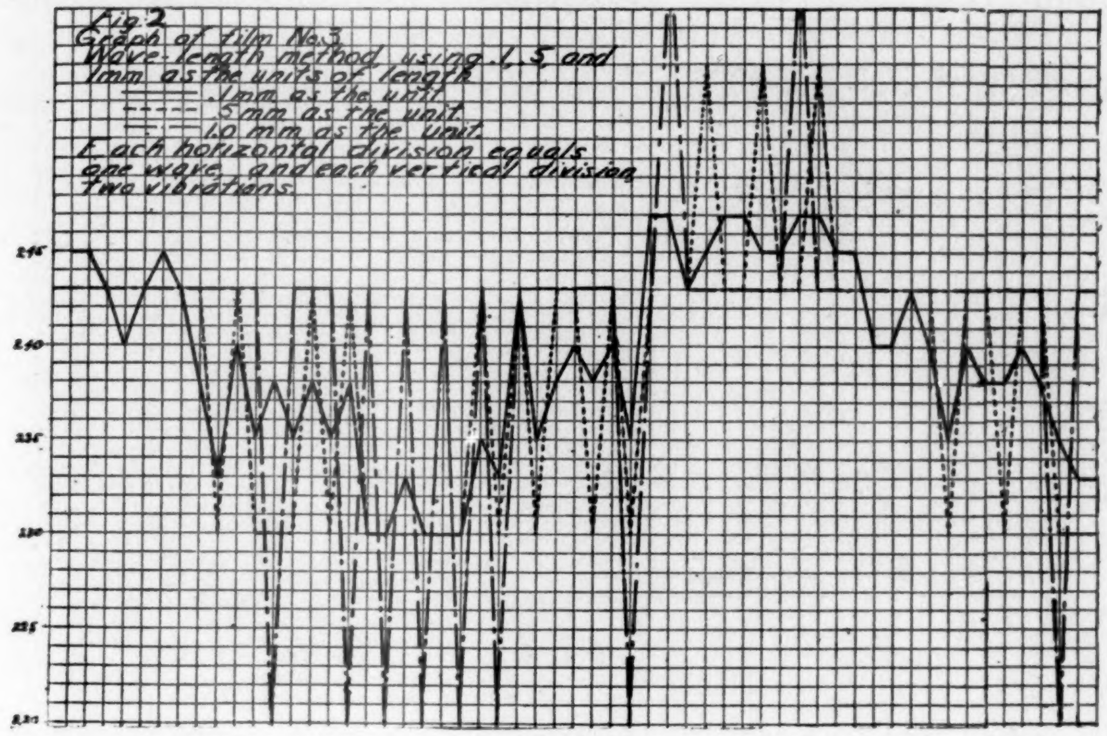


Fig. 2

with a mean wave-length of 20 mm., the readings were made in terms of .005 wave-length, or .1 mm.

However, just as soon as this relationship is lost, the agreement ceases. Accordingly, the results gained from different units will be discussed independently for the two methods, cross-reference being made only for purposes of comparison.

Fig. 2* shows the results when a film is measured by the wave-length method, using .1, .5, and 1.0 mm. as the units of length. In this graph the wide fluctuations recorded by the larger units are apparent. There are changes in wave-length so small that a large unit of length either exaggerates them considerably or else

* Fig. 1, a sample film, is omitted because samples are shown in the foregoing article.

ignores them altogether. If these small changes are to be included, and yet not exaggerated, it is evident that with the wave-length method the unit of measurement should be no larger than .1 mm.

With the time-line method, the unit of length most frequently used has been that of .1 wave-length, with a time block of .01 second. Fig. 3 shows the pitch readings obtained by using three

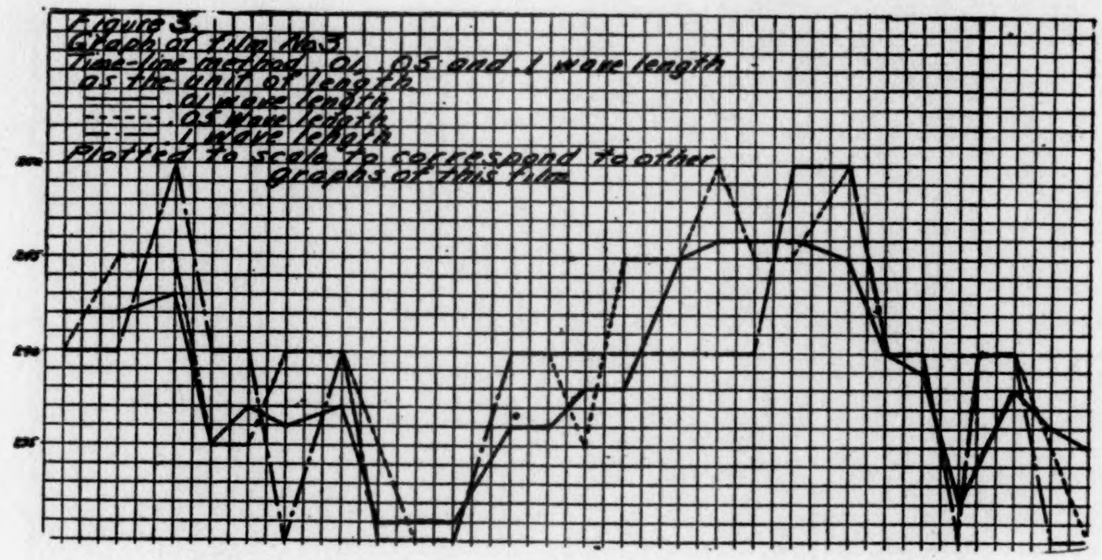


Fig. 3

units, .01, .05, and .1 wave-length. Again, the tendency of the larger unit to ignore or exaggerate the small changes is evident. In this case, however, the disagreement between the various units is not so striking as it was with the wave-length method. This is due to the grouping effect of the time-line method; very small changes in pitch are ironed out by grouping two or more waves into one reading. This grouping is independent of the size of the unit of length. Nevertheless, the statement is again true, that to avoid either ignoring or exaggerating small changes, the unit should be of the finer sort.

B. Units of grouping. When reading by the wave-length method, there may be conditions under which it is perfectly justifiable to group two or more vibrations into one reading. The results, when readings are thus grouped by the wave-length method, are shown in Fig. 4. Here a very definite smoothing is gained from grouping the individual readings. The wide and

abrupt fluctuations recorded by measuring each wave are eliminated when two or three waves are measured and the total distance divided by the number of waves occurring within it. Assuming consistency of measurement, the results obtained by grouping are not different from those which would be obtained by arithmetically averaging the individual readings.

Fig. 5 shows a similar ironing out process when two or three time blocks are grouped into one reading. Here, however, the difference between the various units is not so apparent, because

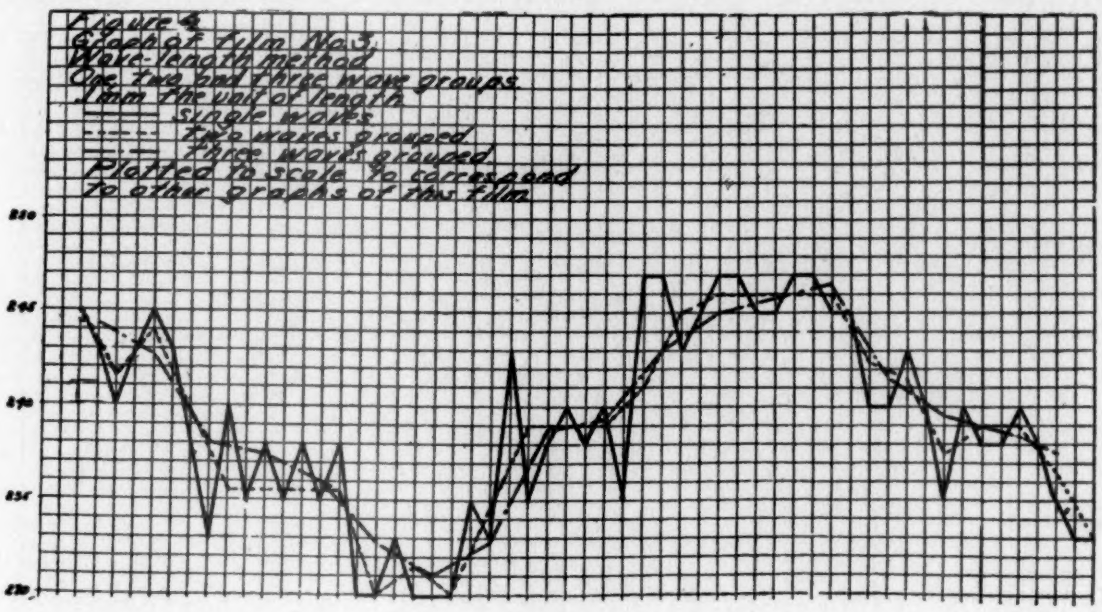


Fig. 4

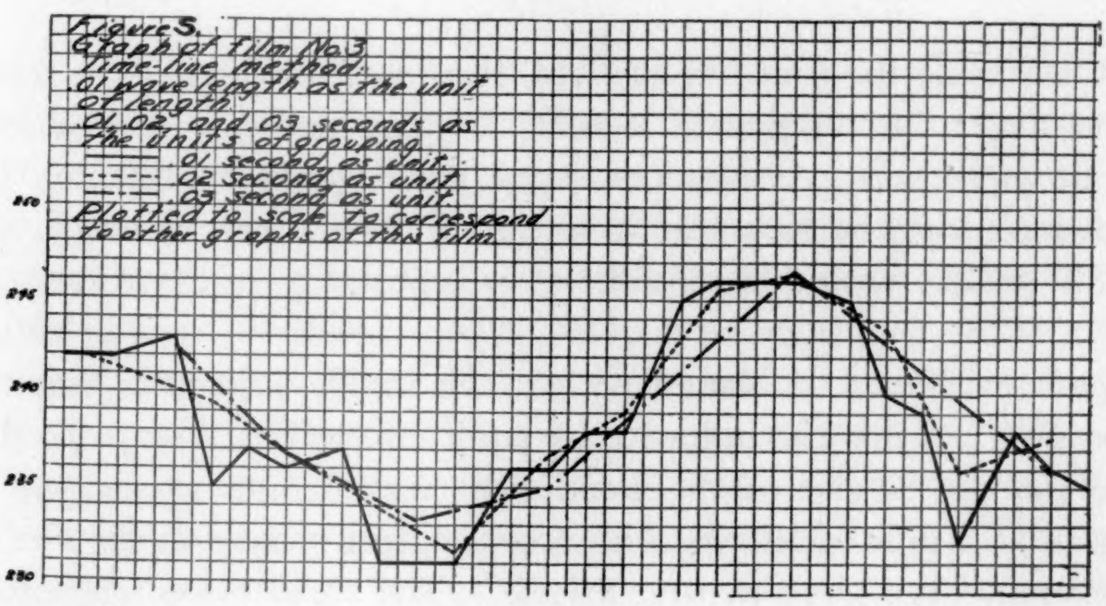


Fig. 5

the one time block unit already represents a certain amount of grouping of individual vibrations.

The results of this grouping of vibrations by the time-line method are seen in Fig. 6, where the lines show the vibration-by-vibration readings made by the wave-length method compared with the readings made with a unit of one time block by the time-line method. Both sets of readings are based on small units of length, *i.e.,* .1 mm. and .01 wave-length.

Influence of the pitch of the sound in the choice of units: A. The unit of length. Rising pitch means a shorter wave-length.

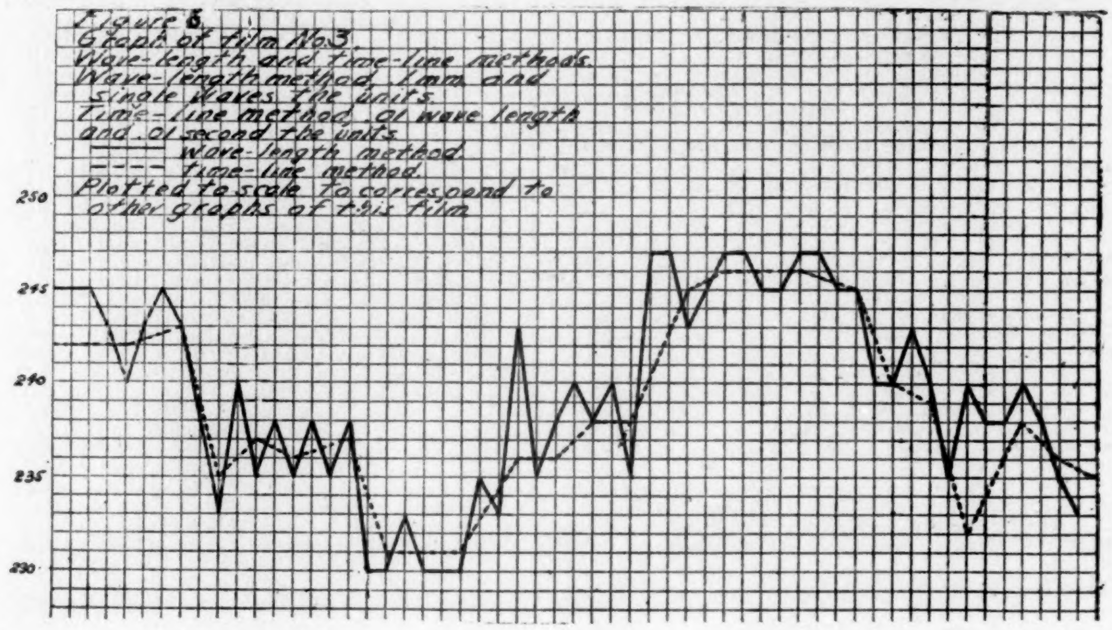


Fig. 6

When using the time-line method, therefore, the higher the pitch, the larger the fraction of a wave-length which can be used as a unit of length. A sound having a wave-length of 10 mm., for example, may be measured in terms of .005 of a wave-length and still remain within the limits of practicability of measurement. But if the frequency be doubled, then, in order to remain within the same limit, .01 wave-length is the smallest fraction that can be used. Thus the influence of pitch on the time-line method is to change the size of the fraction of wave-length which may be used as a unit of length, with a consequent change in the size of the minimum pitch step recordable. The smaller the fraction of wave-length used, the smaller the minimum recordable pitch step.

So far as the wave-length method is concerned, the unit of length is unaffected by a change in pitch. But the value of that unit in vibrations changes decidedly with the pitch. At 128 d.v., with the rate of exposure of the film assumed here, .1 mm. is equivalent to .64 d.v., while at 256 d.v. its value has increased to 2.61 d.v. Thus the effect of a change in pitch is to change the size of the minimum recordable pitch step, whichever method be employed, so long as the rate of exposure of the film is unchanged.

In view of this influence of pitch on the units of length, diagrams have been prepared showing the minimum pitch steps

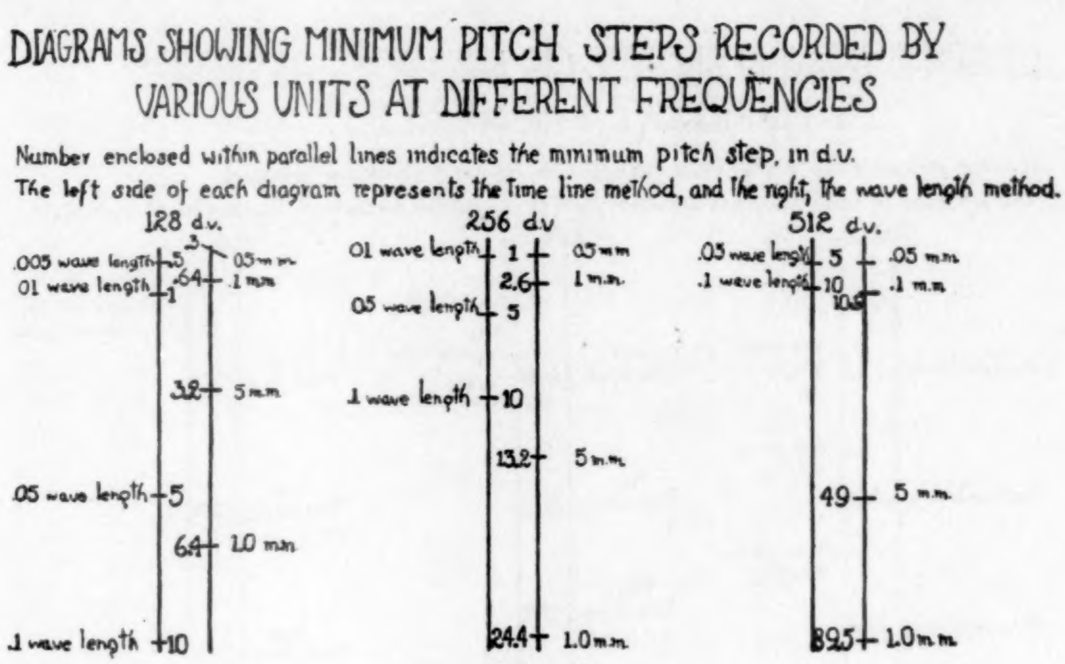


Fig. 7

recordable by various units of length at different frequencies for both the wave-length and time-line methods. Fig. 7 shows these diagrams, which were obtained by finding the difference between pitch readings given by two measurements which differed by the amount of the unit in question.

According to the calculations on which these diagrams are based, at a frequency of 128 d.v., the wave-length method may be used with a unit of .05 mm. to record a pitch step of .3 d.v.; while the time-line method may be used with a unit of .005 wave-length to record a step of .5 d.v. At this same pitch, using the wave-length method with a unit of .1 mm. will record a step of

.64 d.v., while .01 wave-length with the time-line method will register a change of 1 d.v. Units of .5 mm. and 1 mm. with the wave-length method will give steps of 3.2 and 6.4 d.v., respectively; while the time-line method can be used with units of .05 and .1 wave-length to record steps of 5 and 10 d.v. Similarly, by reference to the other diagrams included in this figure, we can determine exactly the minimum pitch step recordable by using either of the two methods with any unit, and at any of the frequencies given.

B. The unit of grouping. The pitch of the sound being measured has no effect on the unit of grouping when the wave-length

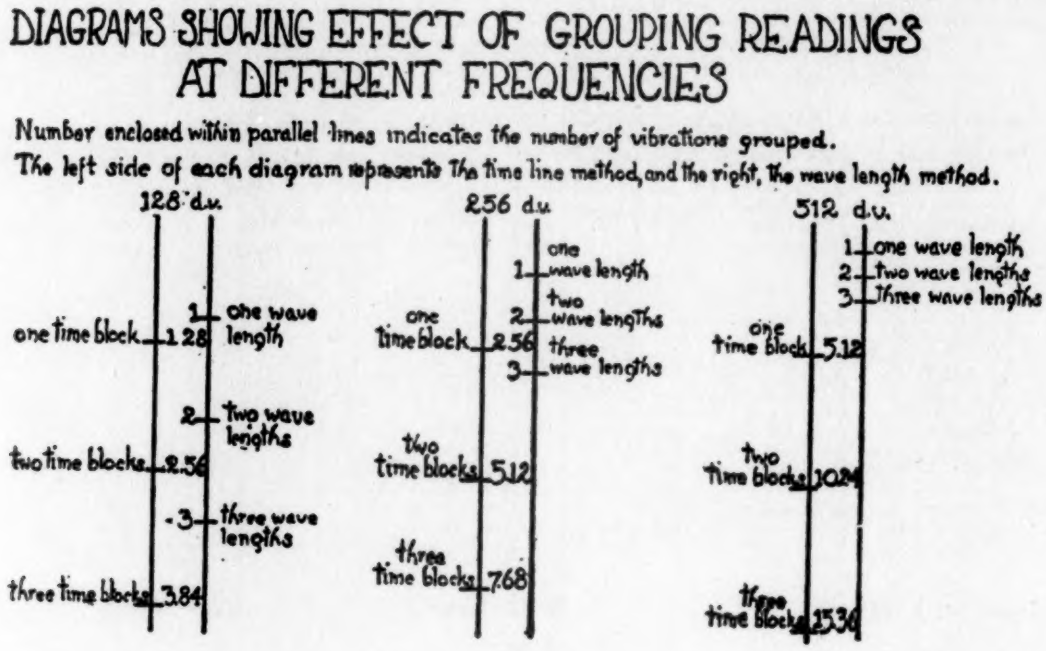


Fig. 8

method is being used. But the case is different for the time-line method. Here, the number of individual vibrations which will be combined by one or more time blocks will depend upon the frequency. In other words, the higher the frequency, the more vibrations will occur in the length of time which is selected as the unit.

The diagrams shown in Fig. 8 make clear this grouping.

At 128 d.v., one time block of .01 second will group 1.28 waves in each reading; two time blocks will group 2.56 waves, and three time blocks, 3.84 waves. Similarly for the other fre-

TABLE IV. *Pitch readings obtained from one film by the wave-length and time-line methods using various units*

	Wave-length method					Time-line method				
	Single waves			Groups in .1 mm.		Single time blocks			Groups in .01 wave length	
	(1) .1 mm.	(2) .5 mm.	(3) 1. mm.	(4) Two's	(5) Three's	(6) .01 wave	(7) .05 wave	(8) .1 wave	(9) Two's	(10) Three's
1....	245	243	243			242	240	240		
2....	245	243	243	245	244.3				242	
3....	243	243	243							
4....	240	243	243	241.5		242	245	240		
5....	243	243	243							
6....	245	243	243	244	242.6					
7....	243	243	243			243	245	250		242.5
8....	238	243	243	240.5						
9....	233	230	243		238	235	235	240	239.4	
10....	240	243	243	236.5						
11....	235	230	243			237	235	240		
12....	238	230	220	236.5	237.6					
13....	235	230	243			236	240	230	236.6	236.6
14....	238	243	243	236.5						
15....	235	230	243		236					
16....	238	243	220	236.5		237	240	240		
17....	230	230	243							
18....	230	230	220	230	232.6	231	235	230	234	
19....	233	230	243							
20....	230	230	220	231.5		231	230	230		233.1
21....	230	230	243		231					
22....	230	230	220	230		231	230	230	231.4	
23....	235	243	243							
24....	233	230	220	234	232.6					
25....	243	243	243			236	240	240		
26....	235	230	243	239						
27....	238	243	243		238.6	236	240	240	236.8	235
28....	240	243	243	239						
29....	238	230	243			238	235	240		
30....	240	243	243	239	239.3					
31....	235	230	220			238	245	240	238.8	
32....	247	243	243	241						
33....	247	243	269		243					
34....	243	243	243	245		245	245	240		241.1
35....	245	255	243							
36....	247	243	243	246	245	246	250	240	245.5	
37....	247	243	243							
38....	245	255	243	246		246	245	240		
39....	245	243	243		245.6					
40....	247	243	269	246		246	245	250	246.1	246.2
41....	247	255	243							
42....	245	243	243	246	246.3					
43....	245	243	243			245	250	250		
44....	240	243	243	242.5						
45....	240	243	243		241.6	240	240	240	243.4	
46....	243	243	243	241.5						
47....	240	243	243			239	240	240		241.8
48....	235	230	243	237.5	239.6					
49....	240	243	243			232	240	230	235.8	
50....	238	243	243	239						

quencies given in the diagrams—the higher the frequency, the larger the number of waves grouped with any unit.

Figs. 7 and 8 show what should result from reading by the two methods and in various units. Table IV gives the readings actually obtained from a film taken from a trained voice with the two methods and the various units discussed. In this table, consecutive readings are placed in vertical columns under their appropriate headings, one column for each of the units of length and grouping possible with the two methods, ten in all. Further, the readings are so spaced that a horizontal line drawn on the table will show the readings obtained by the ten different units for any selected location on the film. All readings are horizontally comparable.

The grouping effect can be seen very plainly in columns 4 to 10, inclusive. In columns 4 and 5, two and three waves are grouped into one reading, and this one reading is spaced so as to preserve the horizontal comparability with the readings of the individual waves. The grouping accomplished by the time-line method is evident in columns 6 to 8. At the pitch of these readings each time block of .01 second groups approximately 2.3 waves. Consequently, when single time blocks are read, they group two waves into one reading till the fraction builds up to a whole number. Hence, for this film, every fourth time-line reading includes three waves, and these readings are also spaced so as to make them horizontally comparable with the measurements of individual waves obtained by the wave-length method. When two and three time blocks are grouped, in columns 9 and 10, the readings are placed according to the same principle. Thus, to discover the actual readings obtained through measuring by either method, or in any unit, all that is necessary is to lay a ruler across the table and pick out the various readings in their respective columns.

The readings shown here in the table agree with the theoretical quantities given in Figs. 7 and 8. The ignoring or exaggerating of small pitch changes by the larger units, seen in the table, is in harmony with the minimum recordable pitch steps which were calculated in the diagrams. Similarly, the effects of grouping

found in the table accord with the theoretical results set forth in the diagrams. Thus, from the diagrams and the table, the experimenter may form an idea of the results he will get by using either method, with any unit.

The Speed of the Film

The ideal speed of exposure is that which is sufficiently slow to register a clear impression on the film, and at the same time sufficiently rapid to draw out the photographed waves so that the error in reading may be small.

So far as the time-line method is concerned, a decrease in the speed of the film will result in an increase in the size of the fraction of a wave-length which it is practicable to use as a unit of length, with a consequent increase in the size of the minimum recordable pitch step. For example, if the film is run at a speed which gives a wave-length of 10 mm. for a certain tone, we may measure that tone in terms of .005 wave-length, and thereby record a minimum pitch step of .5 d.v. But if the rate of the film be halved, then the unit for the same pitch is increased to .01 wave-length, with a resulting minimum recordable pitch step of 1 d.v.

But the speed of the film influences to an even greater extent the readings obtainable with the wave-length method. With a decrease in rate, the minimum pitch step recordable with any unit of length increases rapidly. For example, at a speed of 2425 mm. per second, reading in terms of .1 mm. at 128 d.v. will record a minimum pitch step of .64 d.v. But if the speed be reduced one-half, then reading in the same terms will increase the minimum recordable step to 1.34 d.v. Similarly, at a pitch of 256 d.v., a halving of the rate of the film would increase the minimum pitch step recordable with .1 mm. from 2.6 d.v. to 5.77 d.v.

From these examples it is clear that it is important to run the film at a high speed, and further, that the higher the pitch of the sound in question, the more important is this high speed. The limit to the speed set by the necessity for a clear exposure depends

upon the intensity of the light and the sensitivity of the film; but even for low tones it is hardly practicable to run the film much faster than 3000 mm. per second, because as the wave is drawn out the definition of the critical points becomes less sharp.

The rate of rotation of the tonoscope, 2425 mm. per second, has been found to give results which are satisfactory both from the standpoint of clear exposure and of the percentage of error. Using Eastman super-speed motion picture film and a specially adapted lighting equipment consisting of a 10–12 volt, concentrated filament automobile lamp overloaded with 38–40 volts, photographs have been taken at that speed of tuning forks pitched at 512 d.v., of voices as high as 420 d.v., and instrumental tones of 400 d.v.; all of satisfactory clarity. Furthermore, at that speed it is possible to record a minimum pitch step of 1 d.v. by either the wave-length or time-line methods for all frequencies of 256 d.v. or lower. (See Fig. 7, for which the figures were calculated with this speed of the film as a basis.)

There is one way in which the speed of the film may be increased somewhat beyond the rate given above. That is by decreasing the amplitude of the wave on the film. The greater the amplitude pictured, the less time allowed for exposure at any given frequency or speed. Thus, by decreasing the length of the light lever, the same intensity and pitch of sound may be taken at a more rapid speed. The photographs cited above were all taken with good amplitude—15 to 20 mm.; but this amplitude may be reduced somewhat without loss of accuracy in reading. An amplitude of 10 mm., however, has not given satisfactory results when subjected to repeated measurements.

Thus the ideal speed of the film would seem to be somewhere in the neighborhood of 2000 to 2500 mm. per second for all photographs which are to be subjected to accurate measurements.

Conclusions for Part I

So far as the mechanical and subjective details are concerned, there is no appreciable difference between the wave-length and time-line methods. To reach the ultimate refinement of each

the same precautions are necessary. A difference does arise, however, from the grouping effect of the time-line method; a grouping that persists regardless of the time unit employed.

The choice of method may be indicated in the following rule: If the desideratum is information concerning the individual wave-by-wave fluctuations in pitch, then the wave-length method should be used; if, however, the grouping accomplished by the time-line method is allowable, then for exposures of longer than one second the mechanical factors involved would indicate that this method be used.

Concerning the units of length to be used: For the wave-length method the unit should be .1 mm. No purpose for which this method would be used would tolerate a coarser unit. For the time-line method, if only the grosser fluctuations are desired, then the unit may be .1 wave-length; but for fine measurements either .05 or .01 wave-length should be used.

The unit of grouping with either method will depend upon the amount of grouping allowable for the purpose in mind. If all that is desired are the long-time fluctuations, then two or three of the individual measurements may be grouped; but if short-time fluctuations are to be recorded, then the single units should be used.

The choice of a unit of measurement will be influenced by the pitch of the sound photographed. For the wave-length method, the higher the frequency the smaller the unit of length which should be used, for the pitch value of any unit increases even more rapidly than the frequency. For the time-line method, higher frequencies demand smaller units of grouping, due to the fact that with an increase in pitch more waves are grouped within the time block.

The ideal speed of the film, with present equipment at least, is in the neighborhood of 2000 to 2500 mm. per second for all tones within the normal range of the human voice.

Part II. The Fluctuation in Pitch as Measured in Terms of Variability in Wave-Lengths for Consecutive Vibrations

Part I has dealt with the technique of measurements, showing methods available, sources of error, and standards of reliability. Generalizing from the facts there presented and applying the principles to the present data, it is justifiable to assume that the amount of variation which should be attributed to factors which limit the reliability of the reading may represent an average error of plus or minus .05 mm.

Table V shows how this limit of error will operate for different pitches. The fact that this error becomes too large for the present purpose at the higher pitches led to the selection of relatively low tones for this study.

Table V. *The value of plus or minus .05 mm. error at different pitches*

Frequency	Wave length in mm.	Value of .05 mm.	Per cent of a tone
C 512 d.v.	4.75	5.45 d.v.	8
A 428 d.v.	5.68	3.50 d.v.	7
E 320 d.v.	7.60	2.12 d.v.	5
C 256 d.v.	9.49	1.31 d.v.	4
A 214 d.v.	11.35	.97 d.v.	3
E 160 d.v.	15.18	.59 d.v.	2
C 128 d.v.	18.98	.32 d.v.	2
A 107 d.v.	22.70	.23 d.v.	2
E 80 d.v.	30.36	.13 d.v.	1
C 64 d.v.	37.96	.08 d.v.	1

This .05 mm., expressed in per cent of a tone, constitutes what may be called the reading limit, or the amounts by which the values given in the tables and graphs may vary from the actual values on the films. If the pitches as determined by reading deviated from the norm only by this per cent of a tone, obviously the limit of reading would account for all fluctuations recorded. But all sounds examined give mean fluctuation larger than the reading limit. Again, the fact that the wave-by-wave fluctuations in the trained voices add up to form a periodic gross fluctuation indicates that the direction of the fluctuation found through measurement is not controlled by the reading limit. And so the pitch fluctuations found in this study vary, both in size and direc-

tion, independently of the reading limit; and while this limit has some influence on the data, it is not a determining factor in them.

The data to be presented are of basic character, in that they throw light upon the nature of the finer variations in wave-length which are not commonly taken into account when registering and reading musical or speech sounds for the purpose of determining the general trend of the pitch fluctuations. Ordinarily it would be a waste of energy to attempt to read records of music or speech in as minute details as are here dealt with, yet it will be a distinct advantage to know the general character of such variation.

To make these data representative, the performance was freed as far as possible from emotional expression, or interpretation, and the influence of progression of the sound. The performers were asked to sustain a constant tone for about five seconds and the photograph was taken during the third second. The subjects were given ample opportunity to become accustomed to the conditions of the laboratory and were given practice in the sustaining of the tone. The vocal tones were all sung on the vowel *a* as in "father," except where otherwise noted.

In this study all voice tones were of sufficient intensity to give the optical lever a swing varying from 3° to 9°. No subject was asked to give a tone of greater volume than his vocal organs could readily produce, and yet all tones were of sufficient volume to eliminate any tendency for the untrained subject to cramp the vocal muscles. So far as this study is concerned, therefore, the intensity may be disregarded in a consideration of the data.

The cases here presented should be regarded as samples not at all comprehensive, but perhaps sufficiently representative to give a general picture of the feature under discussion. Most of the cases are from the human voice. Those subjects who reported having had one or more years of vocal lessons were considered as having trained voices; all others were classified as untrained. The latter group was composed mainly of graduate students in the departments of psychology and education. A few instrumental tones were used for purposes of comparison; these being taken from common groups of instruments which are either

bowed or blown. The stringed instruments were represented by the cello, sounds being taken from both open and fingered strings. The lip instruments were represented by the cornet and the trombone, the single reed by the clarinet and the double reed by the bassoon. All instruments were played by members of the University band or orchestra who were recognized as good players.

Presentation of the Data

In presenting the data, the records are limited to fifty consecutive vibrations for each tone. In order to appreciate the fluctuations which occur in these fifty waves, four things should be known: first, the number of times the wave-length changes on the basis of the limit of reading; second, the maximum deviation occurring between any two consecutive waves; third, the average variation per wave on the basis of all the waves, both the varying and the non-varying; and, fourth, the average variation of the actual changes.

Item one is a simple numerical statement—how many times there is a detectable change within the fifty waves, or, how many of the fifty waves differ from the one preceding. Item two is also a simple numerical statement of the greatest difference between two consecutive waves. Item three is an average obtained by dividing the sum of the variations, regardless of direction, by 50—the number of waves considered. Item four was obtained by dividing the same sum of the variations by the number of variations within the fifty waves.

In order that all statements concerning variation may be adjusted for pitch level and expressed in the common terminology of music, the wave-length readings are expressed in the tables and graphs in terms of per cent of a whole tone, as computed on the basis of the dominant pitch in the sound.

Table VII shows the number of times the pitch changes during the fifty waves, the maximum pitch change between any two consecutive waves, the average fluctuation per wave and the average fluctuation per change for each of the sounds studied. The extreme right hand column shows the reading limit, also

in per cent of a tone. Table VIII shows the maximum and minimum of these values found in sounds from each source.

When the trained voices are compared with the untrained on the basis of the number of pitch fluctuations, the latter have a wider range of variability. That is, there are untrained voices in which the pitch fluctuations are more numerous than they are in any trained voices examined, and also there are untrained voices which have fewer fluctuations, than any of the trained. A similar condition exists for the maximum pitch change, the average fluctuation per wave and the average fluctuation per change. In each instance the variability of the untrained voices exceeds that of the trained.

Considering the instrumental tones, the greatest number of pitch changes is found in the clarinet, and the least in the cornet; the widest fluctuation between two consecutive waves is found in the fingered 'cello string, with the clarinet second. The greatest average fluctuation per wave occurs in the clarinet, the least in the open 'cello string and the cornet. The clarinet also gives the greatest average fluctuation per change, while the cornet gives the least.

When the instrumental tones are compared with the voice tones, the voices, both trained and untrained, show a wider range of variability in all the measurements made than do any of the instrumental tones with the exception of the clarinet. This may be due, however, in part to the greater number of voices considered.

Table VII also gives the averages of the sounds from each source. According to these averages, the sounds from the open cello string have, on the whole, the least number of pitch changes within the fifty waves, with the bassoon, the trombone and cornet (tied), the fingered cello string, the untrained voices, the clarinet and the trained voices showing an increasing number of fluctuations. When the various sources of sound are arranged according to the maximum pitch fluctuation occurring between any two consecutive waves, the cornet shows the smallest maximum change, while the open cello string, the bassoon, the trombone, the fingered cello string, the clarinet and the untrained and trained voices show increasing maximum fluctuations. The

TABLE VII. *Pitch changes in consecutive vibrations*

	N	AP	TC	MC	FW	FC	RL
Trained Voices	1	311	32	28	10	15	4
	2	265	36	38	10	14	4
	3	238	38	44	8	11	3
	4	273	32	30	10	15	4
	5	121	29	24	6	11	2
	6	160	32	34	4	7	3
	7	171	43	25	8	9	2
	8	133	34	24	6	9	2
	9	153	36	27	10	13	2
	10	115	27	21	5	9	2
	11	144	43	19	5	8	2
	12	249	34	30	8	12	4
		M.	35	29	7	11	
		M.V.	3.7	6.2	2	2	
Untrained Voices	13	106	26	50	7	13	2
	14	135	23	18	4	9	2
	15	205	38	41	9	13	2
	16	140	25	19	4	8	2
	17	152	42	25	12	14	2
	18	160	32	27	4	7	2
	19	125	29	29	7	12	2
	20	170	35	18	5	6	2
	21	125	31	35	6	9	2
	22	107	31	15	6	10	2
	23	166	34	13	3	5	2
	24	124	26	12	4	8	2
	25	163	35	17	6	8	2
	26	409	27	32	10	19	6
	27	145	29	19	5	10	2
	28	136	29	25	6	10	2
	29	141	31	38	7	12	2
	30	140	29	19	7	12	2
	31	138	17	19	3	8	2
	32	154	34	19	5	7	2
	33	112	40	34	14	17	2
	34	177	44	26	10	11	2
		M.	31	25	7	11	
		M.V.	5.3	8	5	3	
Trombone	35	232	32	19	7	12	3
	36	115	21	15	3	7	2
		M.	26.5	17	5	10	
		M.V.	5.5	2	2	3	
	37	229	28	7	2	4	3
	38	308	35	9	4	9	4
		M.	26.5	8	3	7	
		M.V.	1.5	11	1	3	

TABLE VII—(Continued)

N	AP	TC	MC	FW	FC	RL
39	67	30	12	7	12	1
40	224	25	12	5	11	4
41	102	24	18	5	10	2
42	101	12	18	2	10	2
43	101	10	9	2	10	2
44	102	28	18	6	10	2
45	102	12	18	2	10	2
	M.	20	15	4	10	
	M.V.	7.5	3	2	0.4	
46	274	28	31	6	12	4
47	73	27	12	6	12	1
	M.	27.5	21.5	6	12	
	M.V.	0.5	9.5	0	0	
48	58	17	14	5	14	1
49	129	30	18	5	9	2
	M.	23.5	16	5	11.5	
	M.V.	6.5	2	0	2.5	
50	143	35	18	7	10	2
51	430	34	28	13	19	7
	M.	34.5	23	10	14.5	
	M.V.	0.5	5	3	4.5	

N, the numbers of the films.
AP, the average pitch of the sound.
TC, the number of times the pitch changes within the 50 waves.
MC, the maximum pitch change which occurs between any two consecutive waves, expressed in per cent of a tone.
FW, the average fluctuation in pitch per wave, in per cent of a tone.
FC, the average fluctuation per change, in per cent of a tone.
RL, the reading limit, as determined by .05 mm., in per cent of a tone.

average pitch fluctuation per wave gives the following order, least fluctuation first: cornet, open cello string, bassoon, trombone, fingered cello string, trained and untrained voices (tied), and the clarinet. For the average fluctuation per change, the cornet again shows the least fluctuation, while the trombone and open cello string, the trained and untrained voices, the fingered cello string, the bassoon and the clarinet increase in the amount of their fluctuation in the order named.

The four measurements discussed here are all indices of the variation in pitch occurring in supposedly constant tones. Consequently, if the different orders given in the paragraph above be reduced to one by a process of averaging, that will be a general summary statement of the variability of a sound from any source relative to a sound from any other source. In this way, the conclusion is reached that, when all forms of variation are considered, the sounds coming from a cornet are the most steady and consequently the most like the constant tone. Following the cornet, in order of increasing unsteadiness, come the open cello string, the trombone, the bassoon, the fingered cello string, trained and untrained voices, and, last of all, the clarinet.

The above measurements have been concerned with sources of sound in general; that is, all sounds coming from one source have been averaged to give a conclusion concerning that source. Now, however, a question arises concerning the probable similarity of one sound from a source to any other from that source. According to the mean variations, as shown in Table VII when

TABLE VIII. *Maxima and minima of the values shown in Table V*

Source	A	B	C	D	E	F	G
Trained voices....	43	27	44	10	4	15	7
Untrained voices...	44	17	50	14	3	19	5
Trombone.......	32	21	19	7	3	12	7
Cornet..........	25	28	9	4	2	9	4
Cello							
Open..........	30	10	18	7	2	12	10
Fingered.......	28	27	31	6	6	12	12
Bassoon.........	30	17	18	5	5	14	9
Clarinet.........	35	34	28	13	7	19	10

A, the maximum number of times the pitch changes in any tone from the various sources.

B, the minimum number of times the pitch changes in any tone from the various sources.

C, the maximum pitch difference between any two consecutive vibrations found in the sounds from the various sources expressed in terms of per cent of a tone.

D, the maximum average pitch fluctuation per wave, found in any tone from the various sources, in per cent of a tone.

E, the minimum average pitch fluctuation per wave, in per cent of a tone.

F, the maximum average pitch fluctuation per change, found in any tone from the various sources, in per cent of a tone.

G, the minimum average pitch fluctuation per change, in per cent of a tone.

the number of pitch changes per fifty waves is the criterion, the clarinet and the fingered cello string are the sources whose sounds vary least from one to the other. That is, according to the cases presented here, if any two sounds from a clarinet be compared, we should expect them to agree more closely on the number of pitch changes than would two sounds from the cornet. But sounds from the cornet would be more closely comparable, one with the other, than would tones from trained voices, and so on through untrained voices, the trombone, the bassoon and the open cello string.

When the maximum fluctuation between two consecutive vibrations is considered, the source which produces the most closely comparable sounds is the cornet, while the trombone, the bassoon, the open cello string, the clarinet, trained voices, untrained voices and the fingered cello string show increasing mutual disagreement. In the case of the average pitch fluctuation per wave, the tones from the bassoon and the fingered cello string show the smallest average deviation, while those from the cornet, the open cello string, trained voices and the trombone, the clarinet and untrained voices show increasing deviations. For the fluctuations per change, the order changes again, being fingered cello string, open cello string, trained voices, a three-way tie between the trombone, cornet and bassoon, the untrained voices and the clarinet.

If a procedure similar to the one for the averages be followed here, and these rankings be summarized, the various sources give increasing deviations from one sound to another in the following order: cornet, and fingered cello string (tied), bassoon, open

TABLE IX. *Rank of the various sources of sound according to their general variability in pitch and deviation from the mean*

In order of increasing variability in pitch	In order of increasing variability from the mean
Cornet	Cornet
Open cello string	Fingered cello string
Trombone	Bassoon
Bassoon	Open cello string
Fingered cello string	Trained voice
Untrained voice	Trombone
Trained voice	Clarinet
Clarinet	Untrained voice

cello string, trained voices, trombone, clarinet, and untrained voices.

To summarize the results set forth in tables VII and VIII, the following comparative lists may be drawn up, showing the place occupied by each source of sound relative to other sources according to both variability in pitch and dissimilarity between any two sounds from the same source.

The close agreement of the extremes in these two lists is worthy of notice. In general, there is a tendency for the sources which give sounds of small pitch variation also to give sounds which differ but little from one to another, and vice versa.

To give a clear idea of the distribution of the various sounds studied, a series of tables has been prepared, X-XIII, inclusive, showing the distribution of the instances from each source through the various measurements used. In these tables, the nearer the top any instance may be, the nearer it is to the constant tone which was asked for when the sound was produced.

The next step toward getting a quantitative expression of the nature of the fluctuations which come with consecutive vibrations was to rank all sounds photographed, regardless of source, in order of their increasing variance from a constant tone as measured by each of the four expressions: number of pitch changes, maximum fluctuation between two consecutive waves, fluctuation per wave and fluctuation per change. The rankings made for each expression were then divided into ten divisions, and the per cent of the sounds coming from each source falling in each of the ten divisions tabulated. Tables XIV-XVII show the results.

As a final measure several correlations were made. Rank according to number of pitch changes was correlated with rank according to fluctuation per wave, with a resulting coefficient of r, .64, P.E. .08. Similarly, the rank according to the number of pitch changes was correlated with rank according to fluctuation per change, r, .09, P.E. .09. A final correlation between the number of pitch changes and the maximum fluctuation occurring between any two consecutive vibrations yielded a coefficient of r, .43, P.E. .08.

TABLE X. *Distribution of sounds from various sources according to the number of pitch changes within 50 waves*

Number of Change	Voices Tr.	Voices Unt.	Cello Open string	Cello Fingered string	Cornet	Trombone	Bassoon	Clarinet
10–14	..	..	3	..	..	..	..	..
15–18	..	1	..	..	..	..	1	..
19–22	..	..	..	..	..	1	..	..
23–26	..	4	2	..	1	..	..	..
27–30	2	5	2	2	1	..	1	..
31–34	5	6	..	..	..	1	..	1
35–38	3	3	..	..	..	..	..	1
39–42	..	2	..	..	..	..	..	..
42–44	2	1	..	..	..	..	..	..

TABLE XI. *Distribution of sounds from various sources according to maximum pitch fluctuation occurring between two consecutive vibrations*

Per cent of a tone	Voices Tr.	Voices Unt.	Cello Open string	Cello Fingered string	Cornet	Trombone	Bassoon	Clarinet
6–10	..	..	1	..	2	..	..	..
11–15	..	3	2	1	..	1	1	..
16–20	1	8	4	..	..	1	1	1
21–25	4	2	..	..	..	..	..	..
26–30	3	3	..	..	..	..	..	1
31–35	1	3	..	..	..	..	..	..
36–40	2	1	..	..	..	..	..	..
41–45	1	1	..	..	..	..	..	..
46–50	..	1	..	..	..	..	..	..

TABLE XII. *Distribution of sounds from various sources according to average fluctuations per wave*

Per cent of a tone	Voices Tr.	Voices Unt.	Cello Open string	Cello Fingered string	Cornet	Trombone	Bassoon	Clarinet
2–3	..	2	3	..	1	1	..	..
4–5	3	7	2	..	1	..	2	..
6–7	2	8	2	2	..	1	..	1
8–9	3	1	..	..	..	..	..	..
10–11	4	2	..	..	..	..	..	..
12–13	..	1	..	..	..	..	..	1
14–16	..	1	..	..	..	..	..	..

TABLE XIII. *Distribution of sounds from various sources according to average fluctuations per change*

Per cent of a tone	Voices Tr.	Voices Unt.	Cello Open string	Cello Fingered string	Cornet	Trombone	Bassoon	Clarinet
4–5	..	1	..	..	1	..	..	..
6–7	1	3	..	..	..	1	..	..
8–9	4	6	..	..	1	..	1	..
10–11	2	4	6	..	..	..	..	1
12–13	2	5	1	2	..	1	..	..
14–15	3	1	..	..	..	..	1	..
16–17	..	1	..	..	..	..	..	..
18–19	..	1	..	..	..	..	..	1

TABLE XIV. *Per cent of sounds from each source falling within each division when ranked according to number of pitch changes*

SOURCE

	Voices		Cello					
Rank	Tr.	Unt.	Open string	Fingered string	Cornet	Trombone	Bassoon	Clarinet
1	..	4	43	..	..	..	50	..
2	..	9	28	..	50	50	..	..
3	8	14	..	50	..	..	..	..
4	..	..	14	50	50	..	..	..
5	8	18	..	..	..	..	..	..
6	..	14	14	..	..	..	50	..
7	25	4	..	..	..	50	..	..
8	16	9	..	..	..	..	..	50
9	25	14	..	..	..	..	..	50
10	16	14	..	..	..	..	..	..

TABLE XV. *Per cent of sounds from each source falling within each division when ranked according to maximum fluctuation occurring between two consecutive vibrations*

PER CENT FROM EACH SOURCE

	Voices		Cello					
Rank	Tr.	Unt.	Open string	Fingered string	Cornet	Trombone	Bassoon	Clarinet
1	..	..	14	..	100	..	..	..
2	..	17	29	50	..	..	..	..
3	..	12	..	..	..	50	50	..
4	..	9	57	..	..	..	50	50
5	8	17	..	..	..	..	..	..
6	34	..	..	..	..	..	..	..
7	8	17	..	..	..	..	..	..
8	17	4	..	50	..	..	..	50
9	8	12	..	..	..	..	..	..
10	26	12	..	..	..	..	..	..

TABLE XVI. *Per cent of sounds from each source falling within each division when ranked according to increasing extent of pitch fluctuation per wave*

SOURCE

	Voices		Cello					
Rank	Tr.	Unt.	Open string	Fingered string	Cornet	Trombone	Bassoon	Clarinet
1	..	..	43	..	50	..	..	..
2	..	9	..	..	..	50	..	..
3	8	18	..	..	50	..	..	..
4	16	14	28	..	..	..	100	..
5	..	..	..	..	..	..	..	..
6	16	18	14	100	..	..	..	..
7	..	18	14	..	..	50	..	50
8	25	4	..	..	..	..	..	..
9	34	9	..	..	..	..	..	..
10	..	9	..	..	..	..	..	50

NOTE: There are nine sounds which have a fluctuation of 5 per cent of a tone and nine with a fluctuation of 6 per cent. There should be five sounds in each of the divisions of rank, but these two groups make more than enough for three groups. Accordingly, all sounds with a fluctuation of 5 per cent are grouped in rank 4, and all with 6 per cent in rank 6. This explains the absence of percentages in rank 5.

ent of sounds from each source falling within each
anked according to increasing extent
itch fluctuation per change

SOURCE					
Cello					
Open string	Fingered string	Cornet	Trombone	Bassoon	Clarinet
..	..	50	..	..	..
..	..	..	50	..	..
..	..	..	..	..	..
..	..	50	..	50	..
..	..	..	..	..	..
70	..	..	..	..	50
14	..	..	..	..	..
14	100	..	50	..	..
..	..	..	..	50	..
..	..	..	..	..	50

require some interpretation to reconcile
cy. There is, according to the coefficients,
respondence (r, .64) between the number
e fluctuation per wave, but no significant
) between the number of pitch changes
change. This apparent contradiction is
at the extent of the fluctuation per wave
mputation by the number of pitch changes,
the pitch fluctuation per change is so
ords, in the first instance, the sum of the
vided by a constant number, 50, while in
sum is divided by the number of changes.
sum of pitch fluctuations, the greater the
es contained therein, the smaller will be
per change, both absolutely and as com-
tion per wave. Therefore, there is no

st coefficient, there is some tendency for
hanges and the sum of their extents to
ntirely expected and not especially signifi-
cond coefficient, however, leads to a more
i.e., that there is no fixed relationship
the extent of the individual pitch changes.
a fixed relationship which explains why
the first coefficient is only r, .64, when on a purely arithmetical

TABLE XIV. *Per cent of sounds from each sourc*
when ranked according to number o

			SOURCE		
			Cello		
	Voices		Open	Fingered	
Rank	Tr.	Unt.	string	string	Corne
1	..	4	43	..	..
2	..	9	28	..	50
3	8	14	..	50	..
4	..	..	14	50	50
5	8	18	..	..	..
6	..	14	14	..	..
7	25	4	..	..	..
8	16	9	..	..	..
9	25	14	..	..	..
10	16	14	..	..	..

TABLE XV. *Per cent of sounds from each source*
when ranked according to maximum flu
between two consecutive vib

			PER CENT FROM EACH SOU		
			Cello		
	Voices		Open	Fingered	
Rank	Tr.	Unt.	string	string	Cornet
1	..	..	14	..	100
2	..	17	29	50	..
3	..	12	..	..	..
4	..	9	57	..	..
5	8	17	..	..	..
6	34	..	..	..	..
7	8	17	..	..	..
8	17	4	..	50	..
9	8	12	..	..	..
10	26	12	..	..	..

TABLE XVI. *Per cent of sounds from each source*
when ranked according to increasi
pitch fluctuation per wav

			SOURCE		
			Cello		
	Voices		Open	Fingered	
Rank	Tr.	Unt.	string	string	Cornet
1	..	..	43	..	50
2	..	9	..	..	..
3	8	18	..	..	50
4	16	14	28	..	..
5	..	..	..	..	..
6	16	18	14	100	..
7	..	18	14	..	..
8	25	4	..	..	..
9	34	9	..	..	..
10	..	9	..	..	..

NOTE: There are nine sounds which have a flu
tone and nine with a fluctuation of 6 per cent. T
in each of the divisions of rank, but these two grou
for three groups. Accordingly, all sounds with a fl
grouped in rank 4, and all with 6 per cent in rank 6. This explains the absence of percentages in rank 5.

TABLE XVII. *Showing per cent of sounds from each source falling within each division when ranked according to increasing extent of pitch fluctuation per change*

	SOURCE							
	Voices		Cello					
Rank	Tr.	Unt.	Open string	Fingered string	Cornet	Trombone	Bassoon	Clarinet
1	..	9	..	..	50	..	..	..
2	8	9	..	..	..	50	..	..
3	8	18	..	..	..	..	..	..
4	25	9	..	..	50	..	50	..
5	..	14	..	..	..	..	..	..
6	..	..	70	..	..	..	..	50
7	16	4	14	..	..	..	..	..
8	8	18	14	100	..	50	..	..
9	16	2	..	..	..	..	50	..
10	16	2	..	..	..	..	..	50

These correlations require some interpretation to reconcile an apparent inconsistency. There is, according to the coefficients, a certain amount of correspondence (r, .64) between the number of pitch changes and the fluctuation per wave, but no significant correspondence (r, .09) between the number of pitch changes and the fluctuation per change. This apparent contradiction is explained by the fact that the extent of the fluctuation per wave is uninfluenced in its computation by the number of pitch changes, whereas the extent of the pitch fluctuation per change is so influenced. In other words, in the first instance, the sum of the pitch fluctuations is divided by a constant number, 50, while in the second instance this sum is divided by the number of changes. Hence, with any given sum of pitch fluctuations, the greater the number of pitch changes contained therein, the smaller will be the average fluctuation per change, both absolutely and as compared with the fluctuation per wave. Therefore, there is no contradiction.

According to the first coefficient, there is some tendency for the number of pitch changes and the sum of their extents to increase together—an entirely expected and not especially significant condition. The second coefficient, however, leads to a more significant conclusion, *i.e.,* that there is no fixed relationship between the number and the extent of the individual pitch changes. And it is this lack of a fixed relationship which explains why the first coefficient is only r, .64, when on a purely arithmetical

basis we should expect r, 1.0. That is, since there is no fixed relationship between the number and extent of the pitch fluctuations, additional numbers will not always add the same amounts to the sum of the extents.

The third correlation would indicate a tendency for the tones which have the greatest number of pitch changes to have also a few very wide fluctuations. But the coefficient is not high, and only isolated vibrations in each tone are considered. So there is no need to modify the above general statement that there is no fixed relationship between the number and the extent of the pitch fluctuations.

The Vibrato

The fluctuations given in Table VII for the trained voices are calculated on the assumption that the standard for a trained voice should be a rigid tone—a straight line on a pitch graph. But the researches of *Schoen* (4) have shown that a rigid tone is not the standard for a musical voice, but rather that the vibrato is a fundamental attribute of the artistic singing voice; that in this phenomenon lies the beauty of the tone. Since this is the case, as singers strive for beauty of tone they accept as the standard of a properly sustained tone a periodically fluctuating sound—a sine curve on a pitch graph and not the rigid, non-fluctuating tone which the untrained voice attempts to approximate. Consequently, to arrive at a fair estimate of the pitch errors occurring in the trained voices, the fluctuations must be calculated from the sine curve which represents the true standard.

TABLE XVIII. *Pitch fluctuations in trained voices, using the vibrato as the standard of a constant tone*

Number of the film	Fluctuation per wave	Fluctuation per change
1	8	13
2	8	11
3	7	8
4	7	11
6	4	7
7	4	5
8	1	1
9	4	5
10	3	7
11	3	5
12	5	8

Theoretically, this computation should be made by drawing this sine curve as the axis of the graph, and figuring the deviations from that. But for all practical purposes it is sufficient to determine the total vertical distance through which this sine curve moves and subtract this from the sum of all fluctuations. Table XVIII shows the pitch fluctuations occurring in those trained voices in which the periodicity is sufficiently marked to warrant its use as a basis of calculation.

That is, the actual fluctuations per wave for the trained voices are from 1 per cent to 6 per cent of a tone less than when the fluctuations are computed from the standard of a rigid tone, and the average pitch fluctuation per wave is 5 per cent of a tone, or 2 per cent smaller than the same item for the untrained voices. The average pitch fluctuations per change, on this new basis, are from 0 per cent to 8 per cent smaller, and the average is 7 per cent, or 4 per cent less than the average when the rigid tone is used as the basis.

These findings will influence, to a certain extent, the statements made earlier concerning the various sources of sound. Obviously, however, the findings concerning the number of pitch changes and the maximum fluctuation occurring between any two waves will be the same regardless of the standard which is accepted. But in the case of the average fluctuation per wave, the effect of this basis of computation is to put the trained voice into a tie with the open cello string as giving next to the smallest average pitch fluctuation per wave; while in the case of the average fluctuation per change, the trained voices give the smallest average. So far as the maximum and minimum values are concerned, the effect of this computation is to give the smallest values for both measurements to the trained voices, but to affect but slightly the maximum values. To summarize the effect of changing the basis of computation, the list previously drawn up should now be changed so as to put the trained voices in fifth place among the sounds as they are arranged in order of increasing pitch variability. Thus, the trained voice is more true to its standard than is the untrained.

The Glide

For this portion of the study four voice tones were taken in which the pitch rose or fell approximately an octave within the space of a second. Two were taken from a trained voice and two from an untrained. Table XIX shows the various fluctuations as they occur in the two glides compared with the corresponding averages for constant tones taken from Table VII.

TABLE XIX. *Pitch fluctuations in glide tones from trained and untrained voices compared with corresponding fluctuations in constant tones*

	Trained voices		Untrained voices	
	Constant tones	Glide tones	Constant tones	Glide tones
Number of pitch changes	35	43	31	45
Maximum fluctuation between waves	39	40	25	33
Average fluctuation per wave	5	0.2	16	0.8
Average fluctuation per change	7	0.2	11	1

That is, when the glide tones are considered, using the glide itself as a standard, the average pitch fluctuation per wave and per change are much smaller for both trained and untrained voices than in the case of the supposedly constant tones, and that for the trained voice smaller than for the untrained.

There is another significant thing about these glide tones, namely, the difference in accuracy of the voices in rising and falling tones; both the trained and untrained voices have smaller fluctuations on the falling tone. The averages are shown in Table XX.

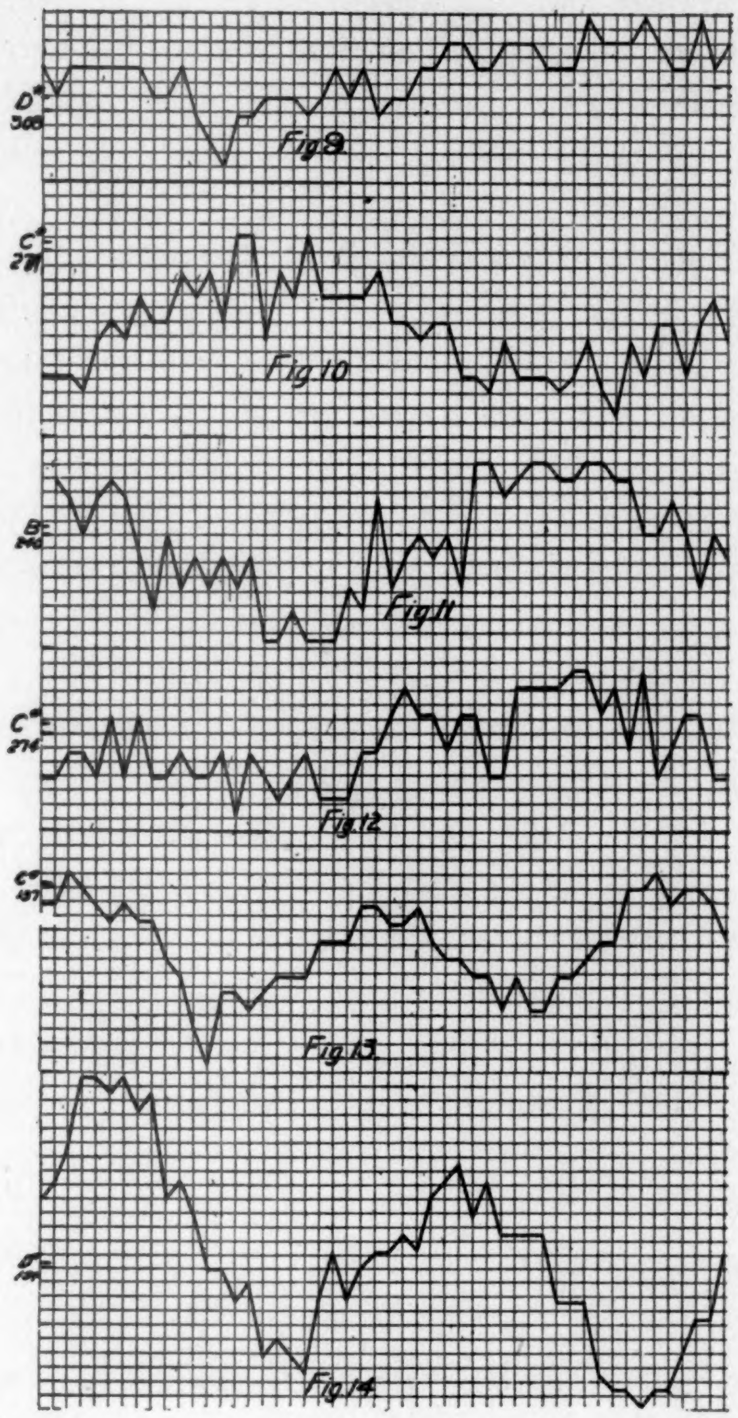
TABLE XX. *Averages for ascending and descending glides*

	Ascending	Descending
Number of pitch changes	44	45
Maximum fluctuation between two waves	41	33
Average fluctuation per wave	0.83	0.02
Average fluctuation per change	1	0.16

Evidently, for both trained and untrained voices, relaxation of the vocal muscles can be accomplished more smoothly than contraction, and probably either of these can be done more accurately than the muscles can be held at a constant tension.

Graphic Analysis

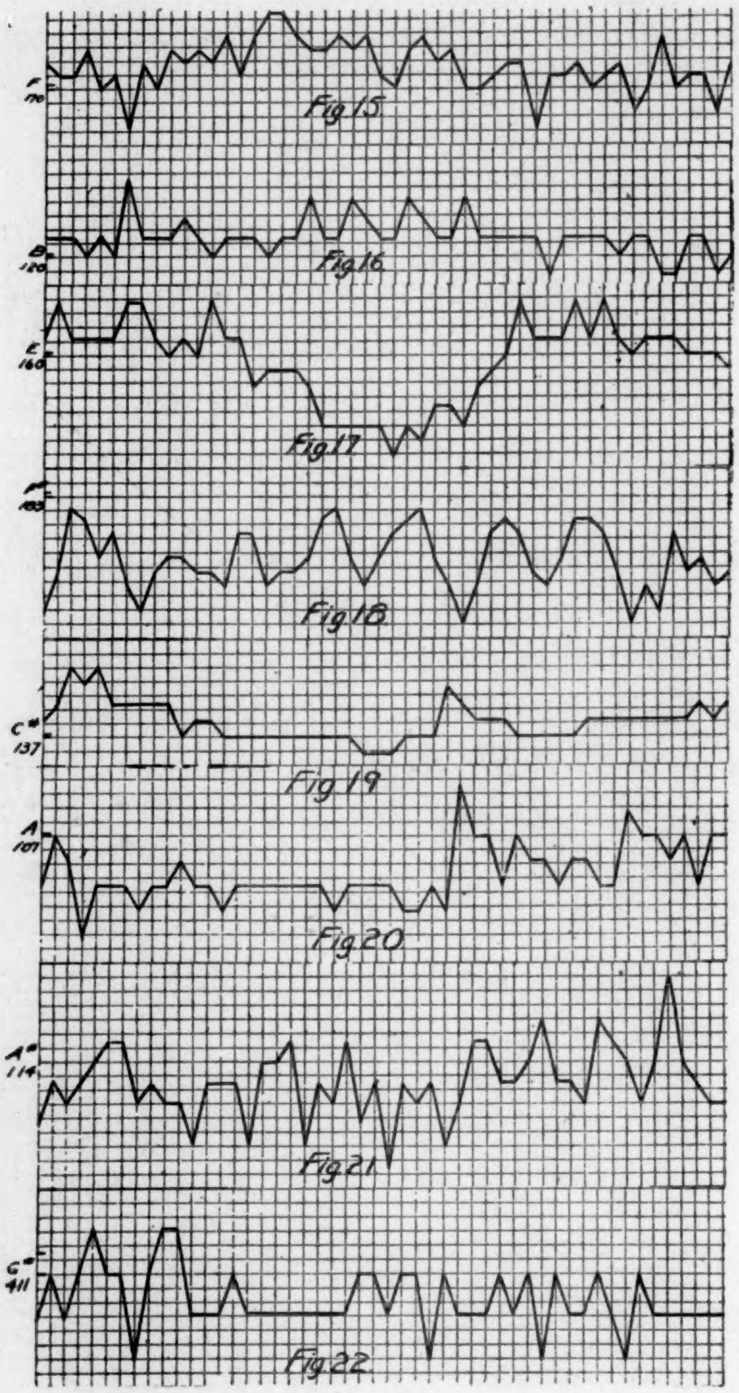
As an addition to the numerical comparison some of the tones studied have been graphed and are shown in Figs 9–39. On these graphs, each division of the abscissa represents one wave and each division of the ordinate indicates a pitch fluctuation of 5 per cent of a tone. The letter and number in the left hand margin show the frequency around which the tone fluctuates,



Figs. 9–14

though not always the exact average pitch. The distance between the two short lines appearing at the left side of the graph indicates the reading limit applying to the tone.

Figs. 9–12, inclusive, show four tones taken from the same voice, that of Mr. Welles, a teacher of music and a professional musician. Mr. Welles, taking his pitch from the score of "Annie Laurie," sang the words "br*ae*s," "bonn*ie*," "m*e*" and "g*a*ve,"



Figs. 15–22

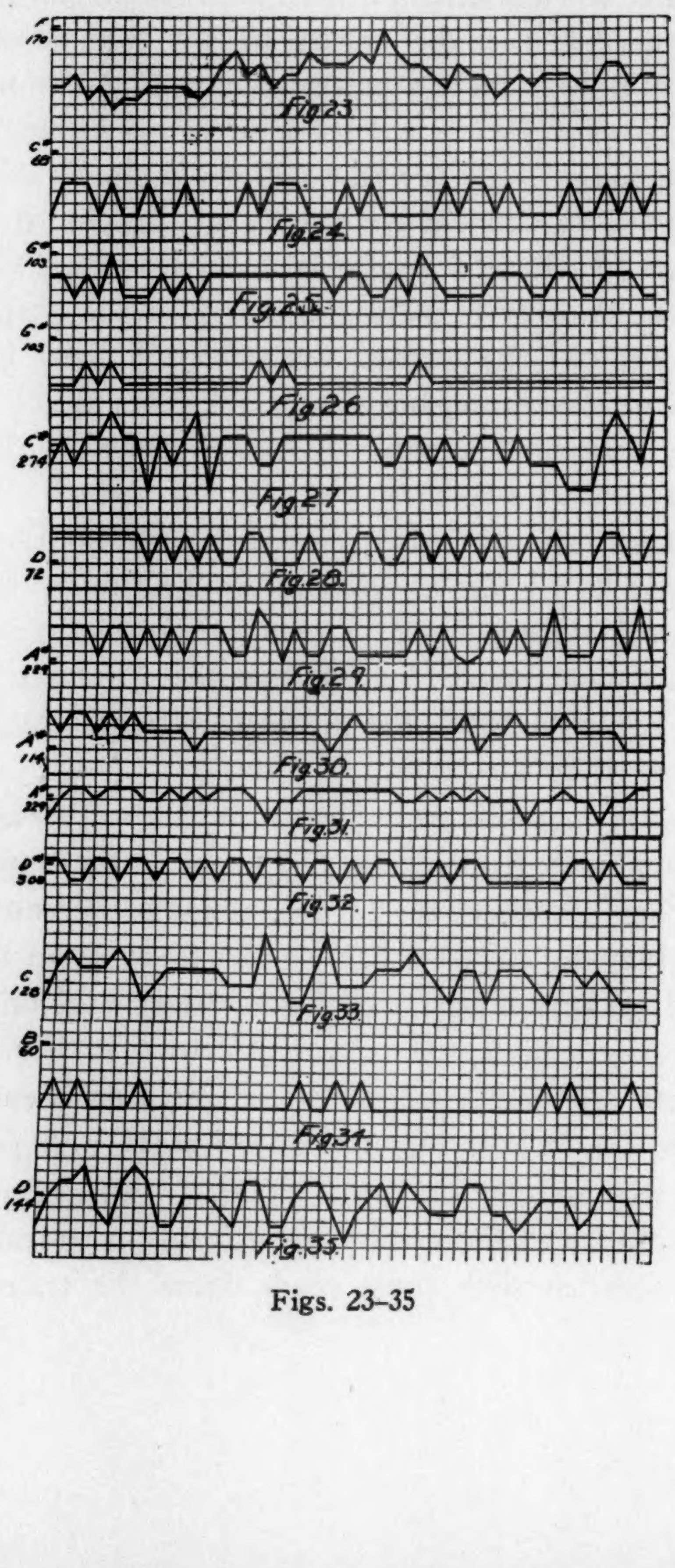
the photographs being taken of the sounds in italics. Although the sounds were taken from "Annie Laurie," the emotional content had very little, if any, influence on the pitch fluctuation, for the subject was asked to sustain the tones as constantly as possible, and further to regard the tones simply as tones with no emotional value to be conveyed to a possible audience. Hence in these four figures are shown the pitch fluctuations which occur in a trained voice when that voice is attempting to hold a constant tone. The regularly recurring, periodic nature of the fluctuations should be noted. Not only is there a wave-by-wave fluctuation but these small fluctuations combine to form a periodic fluctuation of ½ to ¾ of a tone. This periodic pattern is shown more extensively in Figs. 2 to 6, inclusive, which are graphs of the entire tone, a portion of which is represented in Fig. 11. This periodic fluctuation, shown only to a limited extent in the graphs in this section is typical of the trained voice, having been found to a greater or less extent in all but one of the cases studied. And it is this same periodic fluctuation which *Schoen* (4) has shown to be the standard of a constant tone for the trained voice.

Figs. 13 and 14 show another comparative study of tones. The one represented in 13 was as constant as the subject was able to make it, while the other was a vibrato tone from the same voice. The difference between the two is apparent; in fact, when the entire tones are considered, the vibrato fluctuates through twice the range covered by the other.

The remaining graphs are selected to show the largest and the smallest fluctuations as measured by each of the four measures employed. Fig. 15 shows the tone in which the greatest number of pitch fluctuations occurred among the tones from the trained voices, and Fig. 16 the least. The greatest fluctuation occurring between any two consecutive waves is shown in Fig. 11 which was previously discussed. Figs. 9 and 10, also previously discussed, show the largest fluctuation per wave and per change, and Fig. 17 shows the minimum for both.

The erratic form of the graphs made from the untrained voices is in sharp contrast with those made from the trained voices;

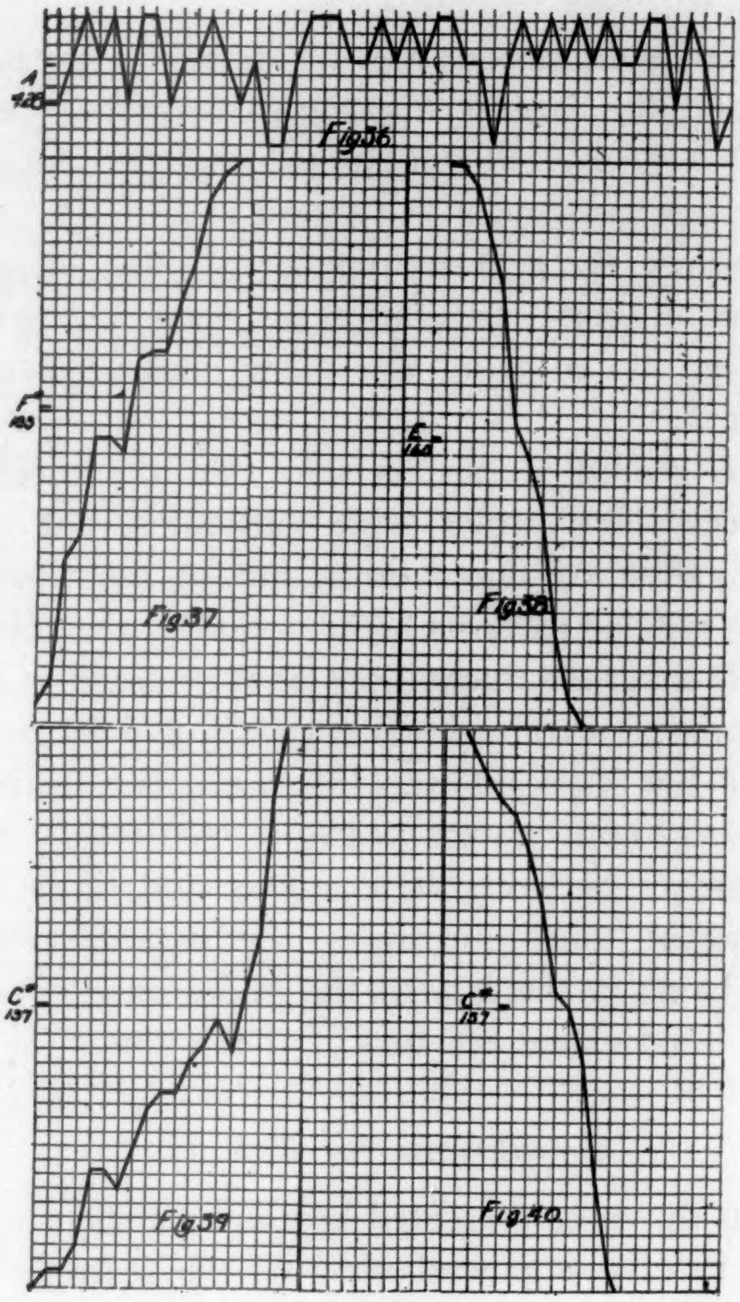
the periodic fluctuations being found in only 13 per cent of the cases examined, and only to a slight extent in these. But not only do the untrained voices show a much more erratic pattern than the trained, but they also vary more widely among themselves. This variation from one to another is plainly shown in Figs. 18–23. Figs. 18 and 19 show, respectively, the most and fewest pitch changes found in any sounds from this source.



Figs. 23–35

Fig. 20 shows the largest pitch fluctuation occurring between any two consecutive waves. Figs. 21 and 22 contain the maximum fluctuation per wave and per change, and Fig. 23 shows the minimum for both.

For the open cello string, Fig. 24 shows the greatest number of changes, the largest fluctuation per wave, and per change; while Fig. 25 shows the largest fluctuation occurring between any two waves. All minima for this source of sound are contained in Fig. 26.



Figs. 36–40

Figs. 27 and 28 show the results from the fingered cello string, the former containing the most changes and the latter the fewest. The extremes of the other measurements occur equally in the two figures.

Representing the trombone, Fig. 29 shows the upper limits of all measurements, while Fig. 30 shows the lower.

Fig. 31 shows the greatest number of pitch changes found in a cornet tone and this maximum occurs in the same sound with the minimum fluctuation both per wave and per change. Fig. 32 shows the least number of pitch changes, which occurs with the maximum of all other measures.

In the case of the bassoon, Fig. 33 shows the greatest number of changes and the largest fluctuation occurring between two waves, and also the least fluctuation per change. All other measurements for this instrument are shown in Fig. 34.

For the clarinet, the greatest number of pitch changes is combined with the minimum fluctuation per wave and per change in Fig. 35. Fig. 36 contains the other measurements of this source of sound.

From these graphs it can be seen that the tones from the various sources show rather wide variations, not only in the number and extent of fluctuations, but in their periodicity as well, the only regular patterns being found in the trained voices.

Figs. 37–40 show the fluctuations as they occur in glide tones; 37 and 38 represent a trained voice, and 39 and 40, an untrained. Here there is but little difference between the trained and the untrained voices, both giving nearly a continuous rise or fall. But the difference between these curves and those made from so-called constant tones illustrates the data shown in Table XVII; there being in the case of the glides only a few instances of a break in the constant rise or fall of the tone.

Conclusions for Part II

In so far as the cases presented here are sufficiently representative samples to give a general view of the features considered, the following conclusions are warranted for Part II:

There are no tones of constant pitch in either vocal or instrumental sounds; the number of pitch changes varying from 10 to 44 within fifty waves, the extent of the average fluctuation per wave from 1 per cent to 14 per cent of a tone, and the average fluctuation per change from 1 per cent to 19 per cent of a tone.

Trained voices are distinguished from the untrained mainly by the greater periodicity of their fluctuations, even in unemotional tones, and also by their greater uniformity to each other and to their standard of a constant tone.

There is no apparent periodicity in the pitch fluctuations of instrumental tones when produced under instructions to keep the tone constant.

There is no fixed relation between the number of times the pitch of a tone changes and the average extent of its fluctuations.

Considering the vibrato as the standard of constancy for the trained voices, and a rigid tone as the standard for all other sources of sound, the various sources, according to the cases studied here, rank in the order of increasing pitch fluctuation:

1. Cornet
2. Open cello string
3. Trombone
4. Bassoon
5. Trained voices
6. Fingered cello string
7. Untrained voices
8. Clarinet

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THE VIBRATO[1]

By Jacob Kwalwasser

Method of photographing and measuring; the parallel vibrato; the opposite relationship vibrato; the pitch vibrato; the intensity vibrato; changes from one type of vibrato to another; tones which have no vibrato; effect of voice placement on the vibrato; effect of vowel quality on the vibrato; effect of voice registers, etc.; effect of intensity changes, etc.; effect of voluntary interference, etc.; influence of age, sex, and training, etc.; the vibrato defined; current literature on the vibrato; summary; bibliography.

This study was undertaken for the purpose of gathering more data on the nature of the vibrato. Such factors as training, sex, age, voice placement and vowel quality were investigated in an effort to ascertain their influence on the pitch, time and intensity fluctuation of the vibrato.[1]

Method of Photographing and Measuring

The photographic method was used exclusively in this study. A strip of super-speed moving picture film was fastened to the drum of the tonoscope (**15**) which is equipped with a synchronous motor to insure regularity in the rate of revolution. A Dorsey phonelescope, mounted on the tonoscope, was used as an optical lever. The observers sang directly into the mouthpiece of the phonelescope. Each photographic record represents a tone sustained from .50 sec. to .75 sec.

The method employed for measuring pitch in terms of wave-lengths was developed and described by *Simon* (**15**). It consists in measuring wave-lengths either individually or in groups with the aid of a vernier microscope. The constant, 2,425 millimeters, the rate of speed per second at which the film passes the point of exposure, divided by the wave-lengths, yields the vibration rate

[1] Grateful acknowledgment is hereby made to Dean Carl E. Seashore, who directed this study. I wish to express my appreciation, also, to faculty and students of the Music School and Model School, who contributed the tones which constitute the subject matter of this thesis.

per second. As demonstrated by *Simon* (15) the pitch and time method of recording have a high order of reliability—finer than demanded for the present purpose.

The intensity readings are less valid than the pitch and time readings. There is first the danger of one or more resonance regions in the phonelescope. The "own" resonance is at 551 d.v. This frequency was therefore avoided in all our tones of the present study. A phono-photograph of the region from 121 d.v. to 400 d.v. reveals no marked period of resonance anywhere in this scale. At the frequency of 275 d.v. which is the sub-octave of the free period, very slight change is found in the amplitude of vibration. Such factors as the length of the optical lever, distance of the singer from the membrane, influence of the tube leading to the membrane, etc., were subjected to little or no experimentation. The following use of the amplitude of the wave as a distinct measure of intensity is therefore intended as merely a rough indication of quantity for which the procedure is perhaps qualitatively adequate.

The Parallel Vibrato

The vibrato is an observable periodicity of pitch or intensity pulsations or both, falling normally within a more or less regular rate of occurrence varying from four to nine per second. The parallel vibrato is one in which the pitch and intensity pulsations are periodic, parallel, and synchronous; *i.e.,* a general tendency for the crests and troughs of pitch and intensity to be more or less coincident in time, extent, and duration.

Table I shows the pitch, intensity, and time measurements of 63 tones of this type. In order to facilitate the discussion of these tones, each column will be taken up separately. Pitches to be reproduced were sounded by means of tuning forks. The observers were instructed to sing the pitch they heard, using a specific vowel or voice placement. In a few cases no standard pitches were given, but generally the pitch used was of a frequency of 220 d.v. Standard pitches are listed under S.P. in Table I. The columns labeled M. show the means in time, pitch,

PARALLEL VIBRATO

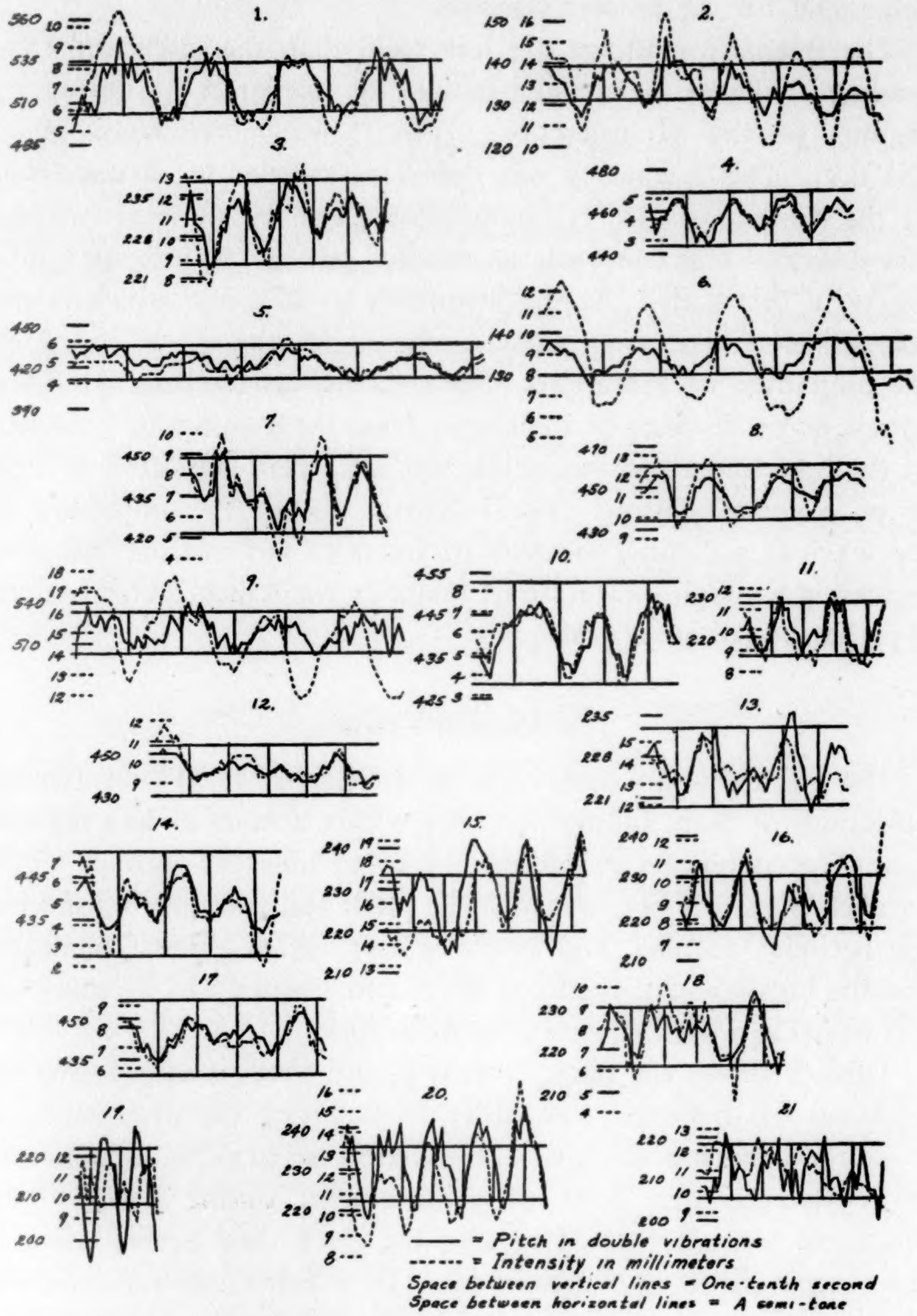


Fig. 1

and intensity, respectively. These columns give the true means, in each case, computed from a series of time, pitch, and intensity readings. The column labeled E.D. gives the extent, *i.e.,* the amplitude of pitch deviations, for each tone in terms of per cent of a tone. E.D. is simply twice the average deviation converted into per cent of a tone. Columns marked A.D. represent measurements of average deviations in intensity and time, while those labeled M.D. represent maximum deviations.

The unit of measurement for the intensity mean is millimeters, but the average and maximum deviations are in terms of per cent of the mean. The unit of measurement for time is in hundredths of a second. The average deviation is in terms of per cent of the mean, also.

The average extent of pitch deviations for the 63 tones of Table I is 23 per cent of a tone; the maximum pitch deviations average 59 per cent of a tone. The mean and maximum intensity deviations are 11 and 50 per cent of the mean respectively. The average duration of pulsation is .16 sec., with an average deviation of 9 per cent.

Fig. 1 contains a graphic representation of 21 tones of this class. In addition to the key to these graphs given in the cut, note that pitch is denoted by d.v. (at the left) and followed by degrees of intensity denoted arbitrarily in terms of millimeters of amplitude. This measurement of amplitude of intensity or vertical displacement of the sound wave was taken directly from the original photograph. The numbers on the graphs correspond to the numbers found in the first columns of the tables.

TABLE I. *Parallel vibrato*

		Pitch			Intensity			Time	
No.	S.P.	M.	E.D.	M.D.	M.	A.D.	M.D.	M.	A.D.
6		134	.27	.69	9	.21	.89	.16	.05
89		267	.25	.66	18	.07	.29	.17	.07
92		273	.26	.78	22	.10	.44	.14	.08
2		135	.57	1.30	13	.09	.43	.11	.07
104		527	.26	1.33	7	.45	1.99	.15	.15
5		424	.20	.44	5	.07	.38	.18	.12
110		465	.18	.53	28	.12	.58	.15	.15
113		333	.19	.63	14	.08	.31	.15	.20
115		551	.21	.55	10	.20	.94	.14	.25
122	256	257	.22	.33	5	.22	1.00	.15	.05

TABLE I—(Continued)

		Ptich			Intensity			Time	
No.	S.P.	M.	E.D.	M.D.	M.	A.D.	M.D.	M.	A.D.
124	256	267	.15	.43	15	.08	.44	.19	.04
1	512	519	.39	1.03	7	.07	.82	.16	.05
9	512	518	.23	.60	15	.10	.36	.16	.05
128		462	.58	1.23	8	.20	.95	.16	.05
129	512	516	.40	1.12	7	.29	1.15	.17	.09
130	512	532	.29	.68	14	.13	.50	.16	.05
131	512	525	.34	.88	9	.27	.88	.15	.05
133		541	.19	.35	7	.13	.54	.17	.04
134		532	.43	.84	6	.26	1.01	.15	.01
150	440	443	.19	.54	7	.16	.63	.14	.00
7	440	435	.13	.44	7	.17	.70	.13	.11
14	440	439	.20	.52	5	.20	1.00	.14	.05
10	440	441	.30	.62	6	.17	.68	.14	.10
155	440	445	.28	.62	6	.12	.63	.15	.00
156	440	444	.11	.18	6	.04	.21	.14	.00
157	440	448	.15	.36	6	.05	.32	.15	.06
158	440	448	.26	.72	3	.08	.52	.15	.06
159	440	441	.21	.36	6	.05	.30	.16	.10
17	440	442	.14	.36	7	.08	.41	.16	.05
8	440	448	.15	.26	11	.07	.29	.16	.09
4	440	457	.23	.43	4	.07	.41	.14	.09
165	440	449	.11	.36	15	.09	.37	.14	.10
12	440	443	.11	.26	10	.07	.32	.16	.05
171	220	219	.22	.52	8	.04	.19	.15	.06
19	220	215	.44	.76	11	.08	.30	.11	.00
21	220	215	.22	.52	11	.07	.32	.15	.12
179	220	220	.17	.44	8	.05	.20	.15	.06
180	220	226	.16	.44	10	.05	.19	.16	.14
181	220	223	.18	.44	18	.05	.25	.15	.09
182	220	224	.13	.44	16	.05	.23	.12	.14
183	320	329	.35	1.39	11	.09	.53	.16	.04
184	128	135	.10	.44	22	.10	.47	.17	.16
192	220	220	.16	.36	12	.04	.24	.14	.10
194	220	220	.18	.60	17	.04	.19	.16	.09
195	220	219	.18	.44	14	.04	.18	.19	.07
196	220	221	.16	.44	14	.03	.18	.22	.13
197	220	219	.17	.44	19	.05	.24	.15	.00
198	220	223	.13	.36	9	.04	.18	.15	.10
11	220	222	.19	.44	10	.09	.39	.15	.18
201	220	221	.26	.52	13	.05	.20	.18	.08
205	220	221	.21	.44	6	.05	.19	.16	.12
13	220	226	.23	.59	14	.04	.22	.22	.09
210	220	226	.20	.59	16	.05	.21	.19	.05
15	220	227	.34	.74	16	.09	.39	.12	.36
20	220	229	.34	.78	12	.12	.64	.14	.07
217	220	225	.19	.52	8	.07	.36	.14	.10
16	220	224	.28	.67	9	.11	.70	.16	.16
3	220	230	.22	.59	11	.10	.49	.18	.08
18	220	223	.27	.52	8	.08	.72	.16	.11
233	220	216	.38	.76	6	.19	1.05	.14	.05
239	220	218	.20	.44	8	.07	.39	.14	.07
121	256	259	.18	.43	6	.06	.36	.19	.04
			.23	.59		.11	.50	.16	.09

For legend see text.

The Opposite Relationship Vibrato

Twenty-four tones, representing 12 per cent of all tones possessing the vibrato, are found in Table II. In this type, the pitch crest is accompanied by an intensity trough, and the pitch trough by an intensity crest. (See Fig. 2.) While the direction of the two factors is opposite, both pitch and intensity are more or less coincident in time, extent, and duration.

The opposite vibrato is similar to the parallel vibrato, as is shown in the following figures.

	Pitch		Intensity		Time	
	E.D.	M.D.	A.D.	M.D.	M.	A.D.
Parallel vibrato	.23	.59	.11	.50	.16	.09
Opposite vibrato	.25	.63	.11	.46	.15	.06

The only significant difference is in the relationship of pitch and intensity.

TABLE II. *Opposite vibrato*

			Pitch			Intensity		Time	
No.	S.P.	M.	E.D.	M.D.	M.	A.D.	M.D.	M.	A.D.
200		160	.22	.53	7	.25	.79	.20	.03
42		155	.59	1.82	16	.14	.57	.18	.16
88	320	313	.22	.80	28	.09	.33	.17	.02
43	512	528	.31	1.05	6	.16	.73	.17	.02
106		417	.22	.44	14	.13	.43	.20	.07
44	512	525	.64	.97	9	.33	1.13	.11	.07
142		187	.16	.43	4	.12	.41	.14	.15
162	880	896	.18	.54	8	.05	.27	.14	.08
174	220	219	.19	.62	11	.05	.25	.14	.08
178	220	218	.15	.36	9	.04	.18	.15	.03
185	220	222	.17	.44	18	.09	.40	.16	.03
186	220	212	.20	.52	8	.03	.16	.16	.06
191	220	220	.17	.44	10	.04	.20	.15	.18
203	110	108	.14	.46	7	.06	.27	.14	.07
204	220	222	.10	.36	11	.10	.50	.13	.04
216	220	221	.17	.40	9	.08	.33	.13	.07
220	220	219	.20	.52	8	.04	.18	.15	.11
223	110	113	.13	.36	8	.05	.27	.13	.00
40	220	218	.17	.36	7	.09	.59	.15	.07
232	220	219	.11	.28	7	.05	.31	.15	.08
39	220	222	.38	.64	8	.19	.68	.14	.07
235	220	217	.60	1.56	6	.19	.71	.15	.05
38		329	.26	.61	6	.14	.73	.15	.03
41	220	219	.25	.72	6	.12	.64	.14	.08
			.25	.63		.11	.46	.15	.06

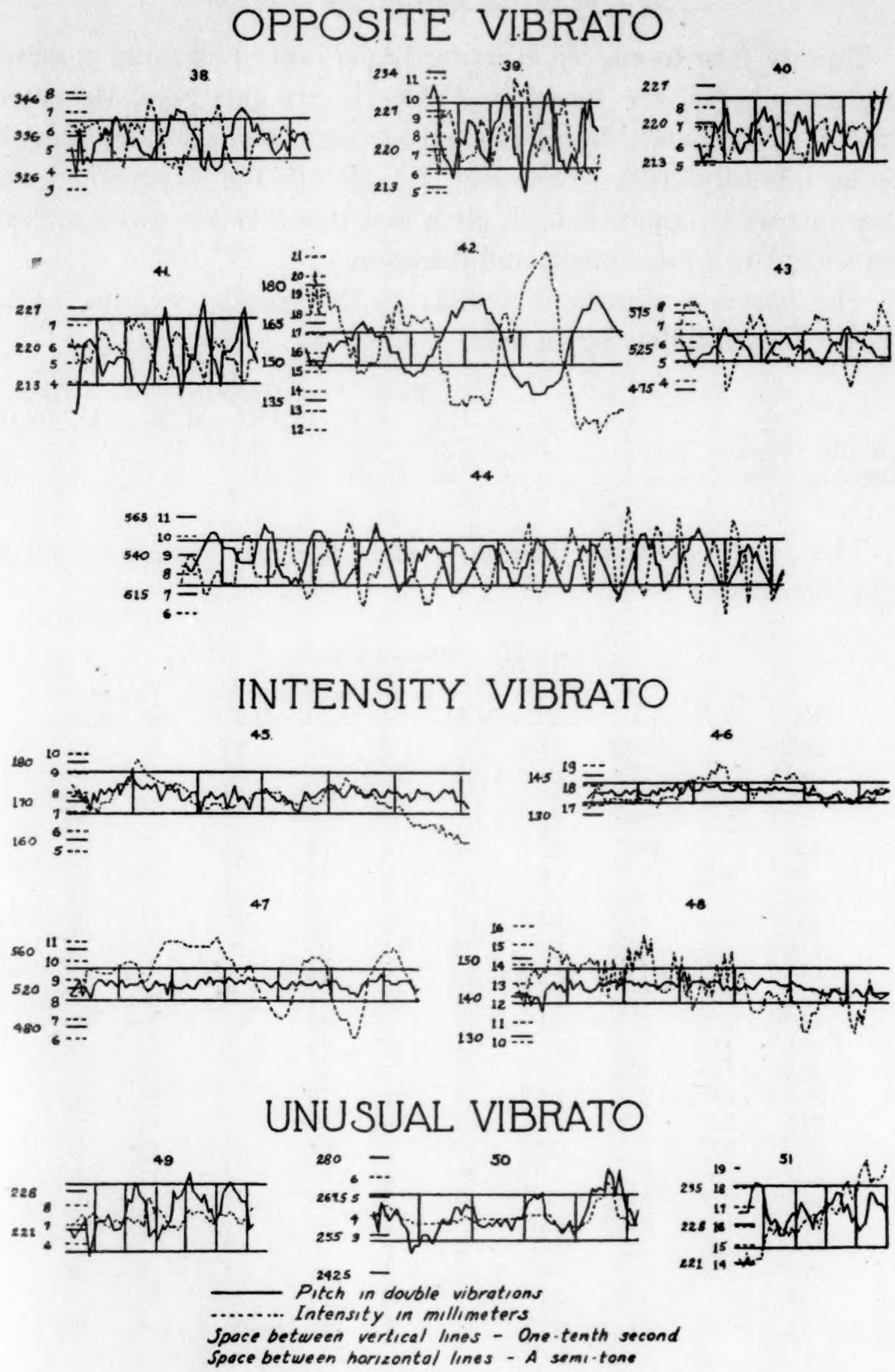

OPPOSITE VIBRATO
38
39
40
41
42
43
44
INTENSITY VIBRATO
45
46
47
48
UNUSUAL VIBRATO
49
50
51
Pitch in double vibrations
Intensity in millimeters
Space between vertical lines - One-tenth second
Space between horizontal lines - A semi-tone

Fig. 2

The Pitch Vibrato

In this vibrato the pitch factor alone reveals the periodicity. The intensity factor, which has been in either the same or opposite phase in former types, is now devoid of any cyclic characteristics, although it does fluctuate irregularly. This type of vibrato is by no means rare. Nineteen, representing 16 per cent of the total number of tones, were found in this study.

The pitch fluctuations for this class are somewhat smaller than those presented before, being E.D., 19 per cent, and M.D., 48 per cent of a tone. The intensity fluctuations are smaller than those found for any of the preceding types. In respect to rate, the pitch vibrato resembles the parallel vibrato.

Table III. *Pitch vibrato*

			Pitch			Intensity		Time	
No.	S.P.	M.	E.D.	M.D.	M.	A.D.	M.D.	M.	A.D.
36	256	251	.18	.43	5	.03	.15	.16	.09
137	220	219	.12	.44	5	.04	.15	.16	.11
30	220	213	.12	.32	18	.04	.06	.15	.03
37	220	211	.16	.44	4	.06	.31	.18	.03
35	440	449	.21	.54	4	.04	.13	.15	.01
170	220	219	.22	.52	8	.04	.19	.14	.07
34	220	220	.22	.52	10	.01	.06	.15	.04
173	220	217	.18	.36	8	.02	.26	.15	.08
175	220	216	.30	.76	8	.07	.29	.13	.05
190	220	221	.22	.60	9	.02	.16	.16	.23
193	220	220	.19	.52	13	.16	.72	.25	.06
208	110	110	.18	.31	6	.03	.17	.14	.20
33	220	224	.13	.33	9	.06	.39	.16	.06
214	220	221	.18	.41	8	.05	.30	.15	.06
219	220	223	.21	.52	6	.03	.16	.16	.11
221	220	221	.17	.52	14	.04	.19	.18	.12
225	220	221	.21	.44	6	.02	.14	.18	.08
31	110	112	.28	.64	5	.04	.23	.13	.08
			.19	.48		.04	.22	.16	.08

The Intensity Vibrato

In this type of vibrato the intensity factor alone reveals cyclic characteristics. Consult Table IV for measurements of the intensity vibrato and Fig. 2 for the graphs.

TABLE IV. *Intensity vibrato*

No.	S.P.	Pitch M.	Pitch E.D.	Pitch M.D.	Intensity M.	Intensity A.D.	Intensity M.D.	Time M.	Time A.D.
45		172	.15	.45	8	.07	.51	.16	.28
46		137	.35	1.13	18	.02	.11	.14	.03
253		144	.13	.44	6	.05	.32	.20	.03
48		143	.13	.44	13	.07	.33	.10	.22
47		525	.10	.43	8	.17	.63	.19	.28
112		547	.11	.55	20	.04	.18	.17	.07
			.16	.57		.07	.35	.16	.15

Changes from One Type of Vibrato to Another

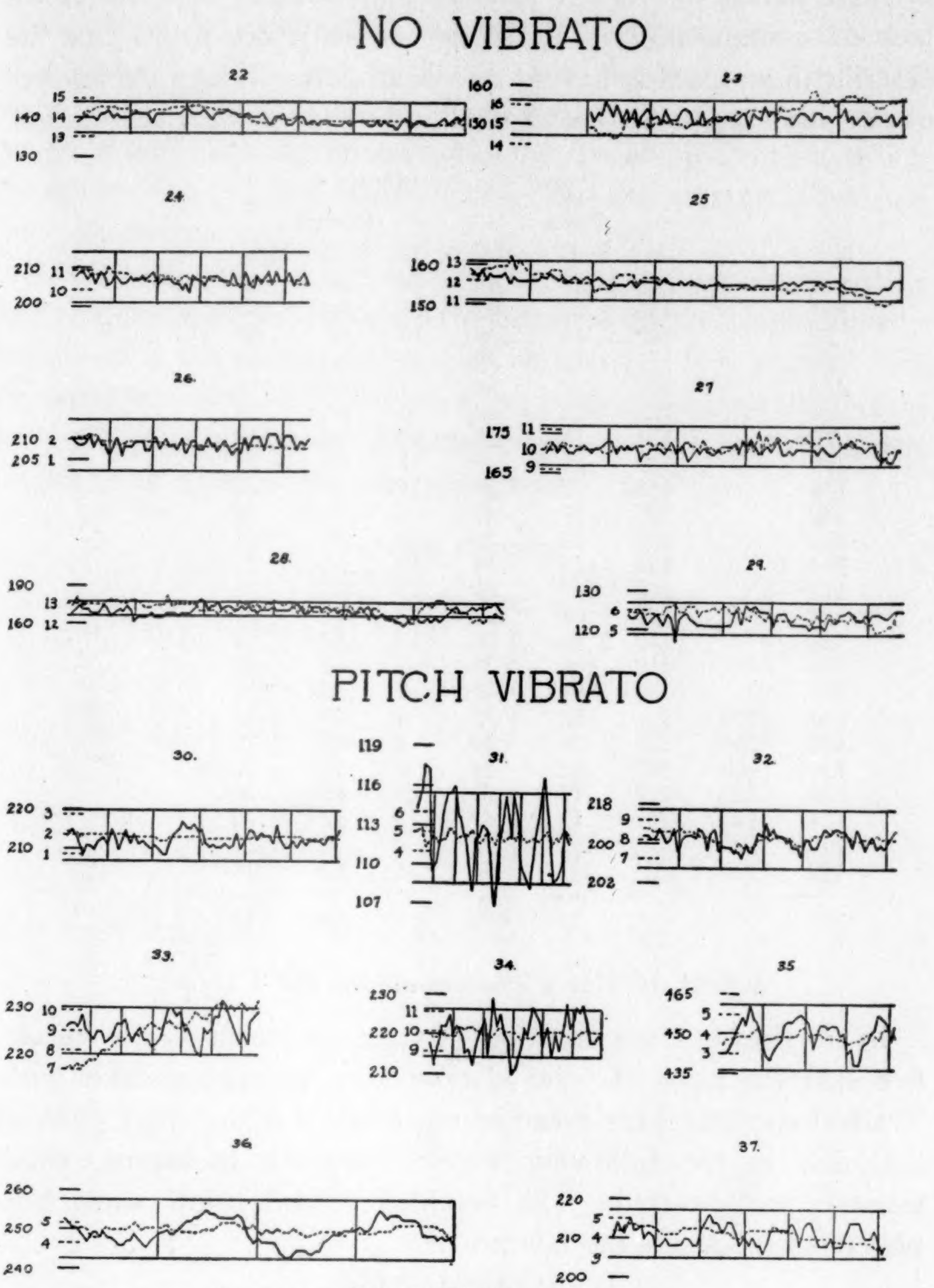
In order to facilitate the discussion of the vibrato, it has been arbitrarily divided into types or classes. An examination of Fig. 1, parallel vibrato, will reveal some cases that are parallel in regard to pitch and intensity, but are slightly out of phase. In tone No. 20 the intensity curve is "skewed" a little to the left of the pitch curve, while in the preceding tone the intensity curve is "skewed" a little to the right. No. 21 is a border-line case, for the phase relationship is almost 180 degrees. If the intensity curve were advanced a little in time, this tone would belong to the opposite vibrato type.

The last three tones of Fig. 2 are classified as unusual types of vibrato, since they change their pitch and intensity relationships from one type to another. No. 49 changes from opposite to parallel; No. 50 begins with no vibrato and ends parallel; while No. 51 resembles No. 49.

Tones Which Have No Vibrato

In a total of 147 tones included in this study, 28 are classified as belonging to the no-vibrato group. Untrained adults contributed 87 per cent of all their tones, and children 41 per cent of all their tones to this class. Only 7 per cent of the tones of trained singers were of the no-vibrato type. Table V gives the measurements of these tones, and Fig. 3 contains the graphs.

The pitch fluctuations may be as large as those found in tones containing the vibrato. But mere fluctuations do not necessarily result in the vibrato. The fluctuations must be progressive and



——— = *Pitch in double vibrations.*
- - - - - = *Intensity in millimeters*
Space between vertical lines = One-tenth second
Space between horizontal lines = A semi-tone.

Fig. 3

cyclic in nature in order to produce the vibrato. It is due to the lack of configuration of pitch or intensity deviations that we describe these tones as having no vibrato, even though the amount of deviation is equal to that found in tones containing the vibrato.

TABLE V. *No vibrato*

		Pitch			Intensity		
No.		M.	E.D.	M.D.	M.	A.D.	M.D.
108		206	.21	.46	14	.04	.22
250		121	.12	.43	15	.09	.36
22		140	.14	.38	14	.02	.07
23		151	.11	.29	15	.04	.14
222		338	.17	.50	7	.04	.18
29		124	.13	.64	6	.06	.34
27		173	.16	.35	10	.02	.12
154		125	.21	.43	7	.05	.25
141		163	.72	1.26	14	.04	.24
140		125	.17	.43	6	.10	.38
252		163	.12	.26	14	.06	.23
254		134	.15	.56	10	.04	.23
172		140	.17	.69	15	.06	.20
25		140	.08	.29	12	.05	.20
28		173	1.03	2.00	13	.02	.09
51		419	.15	.38	9	.12	.60
109		351	.09	.45	9	.06	.38
120	256	266	.12	.37	4	.05	.13
125	256	251	.18	.50	4	.05	.25
139	220	207	.12	.33	4	.13	.20
26	220	207	.17	.25	19	.06	.26
24	220	205	.17	.42	11	.02	.10
207	220	193	.67	1.82	9	.04	.22
199	220	221	.17	.36	11	.05	.14
			.23	.58		.05	.23

Effect of Voice Placement on the Vibrato

In an effort to learn the effect of voice placement on the vibrato, five different types of voice placements were experimented with. Trained vocalists were asked to reproduce a tuning fork pitch of 220 d.v. in the following ways: forward, backward, nasal, throaty, and covered. The results recorded below show how placement influences the vibrato.

	Pitch		Intensity		Time	
	E.D.	M.D.	A.D.	M.D.	M.	A.D.
Backward	.18	.47	.08	.38	.15	.10
Nasal	.17	.41	.04	.21	.15	.06
Throaty	.28	.60	.13	.62	.16	.13
Covered	.23	.56	.11	.48	.15	.07
Forward	.23	.55	.07	.38	.16	.10

Since these computations are based upon five tones each, it is unwise to make unqualified statements concerning the influence of placement. Yet two tendencies are observable. The nasal placement, which produces the nasal quality, results in the smallest pitch and intensity fluctuations, the throaty placement, which results in strained and tense quality, has the greatest pitch and intensity fluctuations.

These two qualities are considered more or less objectionable by voice students, but the matter of amount of pitch and intensity deviations is not mentioned in voice literature. It is possible that this subject of extent of deviation may have a direct relationship with the pleasantness or unpleasantness of tone quality, which results from different types of placement.

		Pitch			Intensity			Time	
No.	Name	M.	E.D.	M.D.	M.	A.D.	M.D.	M.	A.D.
				Forward placement					
170	W.E.	219	.22	.52	8	.04	.18	.14	.07
18	G.J.	223	.27	.52	8	.08	.72	.16	.11
13	H.R.	226	.23	.59	14	.04	.22	.22	.09
190	E.E.	221	.22	.60	9	.02	.16	.16	.23
150	E.C.	443	.19	.54	7	.16	.63	.14	.00
			.23	.55		.07	.38	.16	.10
				Backward placement					
171	W.E.	216	.22	.52	11	.06	.10	.15	.06
41	G.J.	218	.17	.36	7	.09	.59	.15	.07
210	H.R.	226	.20	.59	16	.05	.21	.19	.09
191	E.E.	220	.17	.44	10	.04	.20	.15	.18
7	E.C.	435	.13	.44	7	.17	.70	.13	.11
			.18	.47		.08	.38	.15	.10
				Nasal placement					
34	W.E.	220	.22	.52	10	.01	.06	.15	.04
232	G.J.	219	.11	.28	7	.05	.31	.15	.08
33	H.R.	234	.13	.33	9	.06	.39	.16	.06
192	E.E.	220	.16	.36	12	.04	.24	.14	.10
35	E.C.	449	.21	.54	4	.04	.13	.15	.01
			.17	.41		.04	.21	.15	.06
				Throaty placement					
173	W.E.	217	.18	.36	8	.02	.26	.15	.08
233	G.J.	216	.38	.78	6	.19	1.05	.14	.06
15	H.R.	227	.34	.74	16	.09	.39	.12	.36
193	E.E.	220	.19	.52	13	.16	.72	.25	.06
10	E.C.	441	.30	.62	6	.17	.68	.14	.10
			.28	.60		.13	.62	.16	.13

Covered placement

174	W.E.	219	.19	.62	11	.05	.25	.14	.08
39	G.J.	222	.38	.64	8	.19	.68	.14	.07
214	H.R.	221	.18	.41	8	.05	.30	.15	.06
194	E.E.	220	.18	.60	17	.04	.19	.16	.09
14	E.C.	439	.20	.52	5	.20	1.00	.14	.05
			.23	.56		.11	.48	.15	.07

The Effect of Vowel Quality on the Vibrato

Proceeding as before, trained singers were asked to reproduce a tuning fork pitch on the vowels ä, ā, ē, ō, and ū. The results follow:

	Pitch		Intensity		Time	
	E.D.	M.D.	A.D.	M.D.	M.	A.D.
ä............................	.19	.50	.09	.33	.15	.05
ā............................	.21	.60	.07	.34	.15	.08
ē............................	.19	.46	.07	.23	.16	.08
ō............................	.21	.59	.10	.39	.16	.10
ū............................	.19	.44	.07	.30	.16	.09

The differences in pitch and intensity fluctuations, due to vowel quality, is very slight.

The Effect of Voice Registers on the Vibrato

Vocalists have divided the voice range into three registers, *i.e.,* head, middle, and chest. The chest tones represent, approximately, a little more than a half-octave interval in the lowest range of the voice. The head register consists of approximately the same interval at the top of the voice range. The interval of an octave, more or less, between the head and chest registers is known as the middle register. Only the head and chest tones were experimented with at this time, since practically all other tones of this study are of the middle register type.

Greater differences were found between the head and chest tones in regard to their pitch, intensity, and time fluctuations than between any other two groups of tones found in this study.

	Pitch		Intensity		Time	
	E.D.	M.D.	A.D.	M.D.	M.	A.D.
High tones	.24	.76	.08	.43	.15	.05
Low tones	.17	.44	.05	.28	.14	.10

Before any interpretation is made of these measurements something should be said of the relationship of amplitude to pitch frequency. *D. C. Miller* (9) presents the formula $(n\,A)^2$ and a graph in discussing this subject. "The intensity or loudness of a sound is proportional to the square of the amplitude multiplied by the square of the frequency, that is, to $(n\,A)^2$. A recording apparatus having ideal response must fulfil the following conditions: Let all tones of the musical scale, from the lowest to the highest, and all exactly of the *same* loudness, be sounded one after another and be separately recorded; let the amplitudes of the various responses be measured, and each amplitude be multiplied by the frequency of the tone producing it, then the squares of the products of amplitude and frequency must be constant throughout the entire series."

Miller accompanies this discussion with a graph in which he shows the actual amplitudes of sounds varying in pitch but constant in loudness. By actual measurement the amplitude of C^3 (259 d.v.) is 15 times the amplitude of C^7 (4,138 d.v.), yet the two tones are of equal loudness.

		Pitch			Intensity			Time	
No.	Name	M.	E.D.	M.D.	M.	A.D.	M.D.	M.	A.D.
				Head tones					
222	H.R.	338	.17	.50	7	.04	.18	..	..
38	G.J.	329	.26	.61	6	.13	.73	.15	.03
183	W.E.	329	.35	1.39	11	.09	.53	.16	.04
162	E.C.	896	.18	.54	8	.05	.27	.14	.08
			.24	.76		.08	.43	.15	.05
				Chest tones					
223	H.R.	113	.13	.36	8	.05	.27	.13	.00
250	E.C.	254	.22	.44	5	.04	.28	.14	.10
184	W.E.	135	.10	.64	22	.10	.47	.17	.16
38	G.J.	112	.28	.44	5	.04	.23	.13	.08
203	E.E.	108	.14	.46	7	.06	.27	.14	.07
208	E.E.	110	.18	.31	6	.03	.17	.14	.20
			.17	.44		.05	.28	.14	.10

Effect of Intensity Changes on the Vibrato

Trained vocalists were asked to reproduce the pitch of a tuning fork in the three following ways: pianissimo, fortissimo, and crescendo. Head and chest tones were avoided.

	Pitch		Intensity		Time	
	E.D.	M.D.	A.D.	M.D.	M.	A.D.
Pianissimo	.20	.50	.06	.30	.16	.09
Fortissimo	.20	.47	.09	.48	.15	.07
Crescendo	.35	.94	.07	.35	.16	.07

Since the crescendo begins pianissimo and ends fortissimo, it is not surprising to find that its intensity measurements approximate the average of the extremely soft and loud tones. The pitch measurements for the pianissimo and fortissimo are similar, but the crescendo tones are accompanied by excessive pitch fluctuations. Why the crescendo tones should not represent a compromise in pitch as in intensity is unaccountable. It is possible that the attempt to change the dynamics of a tone results in the loss of pitch control. The time measurements agree with those presented before. An increase in intensity is accompanied by a shorter pulsation rate, which means an increase in the number of pulsations per second.

Fortissimo

			Pitch			Intensity		Time	
No.	Name	M.	E.D.	M.D.	M.	A.D.	M.D.	M.	A.D.
16	H.R.	224	.28	.67	9	.11	.70	.16	.16
4	E.C.	457	.23	.43	4	.07	.41	.14	.09
185	W.E.	222	.17	.44	18	.09	.40	.16	.03
239	G.J.	218	.20	.44	8	.07	.39	.14	.07
204	E.E.	222	.10	.36	11	.10	.50	.13	.04
			.20	.47		.09	.48	.15	.07

Pianissimo

225	H.R.	221	.21	.44	6	.02	.14	.18	.08
165	E.C.	449	.11	.36	16	.09	.37	.14	.10
186	W.E.	212	.20	.52	8	.03	.16	.16	.06
41	G.J.	219	.25	.72	6	.13	.64	.14	.08
205	E.E.	221	.21	.44	6	.03	.19	.16	.12
			.20	.50		.06	.30	.16	.09

Crescendo

207	E.E.	193	.67	1.82	9	.04	.22	.18	.08
3	H.R.	230	.22	.59	11	.10	.49	.13	.07
51	W.E.	229	.17	.41	17	.06	.35	.15	.07
			.35	.94		.07	.35	.16	.07

The Effect of Voluntary Interference on the Vibrato

In an effort to learn what could be done with the vibrato in voluntarily exaggerating and eliminating it, trained vocalists were asked, in turn, to produce tones, with and without the vibrato. In the exaggerated vibrato, the vocalists were asked to make the pulsations as obtrusive as possible, while in the inhibited vibrato they were instructed to maintain a rigid and inflexible tone. The following measurements were obtained:

	Pitch		Intensity		Time	
	E.D.	M.D.	A.D.	M.D.	M.	A.D.
Exaggerated vibrato	.44	1.00	.13	.54	.14	.06
Inhibited vibrato	.20	.52	.12	.55	.15	.08

The exaggerated vibrato sounded like the "highly objectionable" tremolo. The pitch fluctuations produced are almost twice those of the normal vibrato. The intensity fluctuations are also exaggerated, while the attempt to make the pulsations obtrusive resulted in an increase in the number of pulsations per second.

The attempt to inhibit the vibrato was totally unsuccessful, since it was never accomplished. The pitch fluctuations for the "rigid and inflexible" tones resemble those for normal vibrato tones. The intensity readings are approximately the same as those for the exaggerated vibrato. Again, a very insignificant decrease in the pitch fluctuations is accompanied by an increase in the intensity fluctuations, which might be interpreted as a loss of intensity control. The rate of pulsation for the inhibited vibrato is slower than that of the exaggerated vibrato, but faster than the normal rate.

It is evident that the magnitude of pitch and intensity fluctuations may be increased beyond the habitual boundaries, voluntarily, with but little effort; but the attempt to reduce the pitch and intensity fluctuations below the habitual minimum is exceedingly difficult. Complete inhibition of the vibrato fluctuations was beyond the power of the vocalists in all cases here tried.

Inhibited vibrato

			Pitch			Intensity		Time	
No.	Name	M.	E.D.	M.D.	M.	A.D.	M.D.	M.	A.D.
216	H.R.	221	.17	.40	9	.08	.33	.13	.07
102	F.A.	133	.35	.69	11	.13	.47	.11	.10
104	J.W.	527	.26	1.33	7	.45	1.99	.15	.15
133	M.P.	541	.19	.35	7	.13	.54	.17	.04
156	E.C.	444	.11	.18	6	.04	.21	.14	.00
12	E.C.	443	.11	.26	10	.07	.32	.16	.05
21	W.E.	215	.22	.52	11	.07	.32	.15	.12
196	E.E.	221	.16	.44	14	.03	.18	.22	.13
			.20	.52		.12	.55	.15	.08

Exaggerated vibrato

2	F.A.	135	.57	1.30	13	.09	.43	.11	.07
42	J.K.	155	.59	1.82	16	.14	.57	.18	.16
44	M.P.	525	.64	.97	9	.33	1.13	.11	.07
155	E.C.	445	.28	.62	6	.12	.63	.15	.00
176	W.E.	216	.30	.76	8	.07	.29	.13	.05
19	W.E.	215	.44	.76	11	.08	.30	.11	.00
20	G.J.	229	.34	.78	12	.12	.63	.14	.07
195	H.R.	219	.18	.44	14	.04	.18	.19	.07
235	E.E.	217	.60	1.56	6	.19	.71	.15	.05
			.44	1.00		.13	.54	.14	.06

Influence of Age, Sex and Training on the Vibrato

1. *Age.* Seven children, ranging in age from eight to sixteen, with no special training in music, contributed tones for this section of the study. They were asked to sing tones which were well within their range and easy to sustain. These tones were photographed and measured. It was found that three of the eight children failed to produce any trace of the vibrato in their tones.

	Pitch		Intensity		Time	
Children	E.D.	M.D.	A.D.	M.D.	M.	A.D.
With vibrato	.17	.54	.09	.37	.17	.12
Without vibrato	.11	.42	.12	.54	...	...

The intensity fluctuations are smaller than those obtained from the tones of adult vocalists. In adult voices, however, tones devoid of the vibrato have smaller mean and maximum intensity deviations than tones containing the vibrato. The reverse of this situation is true in reference to the tones of children. Even though generalizations must be made with reservations due to the

limited sampling of children's tones, it appears that the child's voice is more flexible from the standpoint of intensity and less flexible than the adult's in regard to pitch.

2. *Sex.* The following data give some indication of the influence of sex. They include the measurements for trained voices only:

	Pitch		Intensity		Time	
	E.D.	M.D.	A.D.	M.D.	M.	A.D.
Female	.25	.76	.30	.80	.15	.07
Male	.22	.63	.26	.42	.14	.08

Men's voices do not fluctuate as much in either pitch or intensity as do women's voices. Of the total number of tones sung by trained men, 9 per cent were without the vibrato, while only 4.5 per cent of all tones sung by women were devoid of the vibrato. It might be said, then, that the vibrato is more conspicuous in women's voices than in men's and also more frequently present.

3. *Training.* Proceeding as before, we find the following measurements for the trained and untrained:

	Pitch		Intensity		Time	
	E.D.	M.D.	A.D.	M.D.	M.	A.D.
Trained singers with vibrato	.23	.56	.09	.36	.16	.08
Trained singers without vibrato	.21	.55	.06	.20	...	...
Untrained singers with vibrato	.20	.62	.08	.35	.15	.12
Untrained singers without vibrato	.26	.54	.05	.21	...	...

It is evident that the vibrato appears in the tones of the untrained as well as the trained singers; but, while the above data do not indicate the frequency of appearance on the basis of training, it was found that 93 per cent of all tones produced by trained vocalists and only 27 per cent of all tones produced by untrained singers, contained the vibrato. On the basis of training alone, it is possible to predict the presence of the vibrato with a high degree of accuracy.

The above data reveal only slight differences in the pitch fluctuations for the four types. There is a definite tendency, however, for the intensity fluctuations to be greater in tones containing the vibrato than in tones devoid of the vibrato, regardless of training.

The Vibrato Defined

Prior to the study of the writer on the nature of the vibrato, two factors were isolated and measured; namely, pitch and intensity. The third factor of the vibrato, that of time, was described as relatively constant. Not only was the time factor believed to be relatively constant, but the pitch and intensity relationship was assumed to be rigidly fixed and always parallel. The six conclusions as formulated by *Schoen* (16) reveal what was attributed to the vibrato prior to this investigation.

(1) "The vibrato is a fundamental attribute of artistically effective singing voice in that it is a medium for the conveyance of emotion in vocal-expression.

(2) "The vibrato is a manifestation of the general neuro-muscular condition that characterizes the singing organism.

(3) "The psychological effect of the vibrato is probably due to the fact that the human ear has, because of the behavior of muscle under emotional stress, come to associate trembling with emotional experiences.

(4) "The voice that possesses the most constant vibrato, constant in its presence in the tones throughout the range of the singer's voice and of an amplitude and intensity not obtrusive to the ear, but of sufficient intensity to be easily audible, has the best effect on the hearer, provided the other factors that enter into artistic singing are present.

(5) "The rate of the vibrato is relatively constant, of approximately six pulsations per second.

(6) "The intensity fluctuations are synchronous with the pitch fluctuations, wave by wave for both rate and extent."

The first four conclusions as formulated by Schoen stand unimpaired by the evidence submitted in this investigation, but the last two conclusions must be modified considerably, for it has been found that the rate of pulsations is quite variable and that the pitch and intensity relationship is not always parallel or synchronous.

In defining the vibrato, it is necessary to state that the vibrato consists of an observable periodicity of either pitch or intensity pulsations, or both, in a more or less regular time sequence or relationship, varying in rate of occurrence from 4 to 9 per second. It is a phenomenon of three variables; namely, pitch, intensity, and time.

Current Literature on the Vibrato

The vibrato has long been a subject of controversy among musicians and music critics. The literature on the subject is so confusing that it is next to impossible to glean a clear conception of the nature, causes, or desirability of the vibrato. Most of the literature available deals with the desirability of the phenomenon. Some critics maintain that it is desirable when not used excessively; others hold that even the slightest manifestation of it is objectionable.

In an effort to establish the status of the vibrato and tremolo, I shall resort to direct quotation from the works of voice critics on the subject. It must be borne in mind that these quotations are formulations of esthetic judgments and involve the desirability of the vibrato and tremolo primarily. Occasionally we find information or observations on how the vibrato is produced and what it attempts to accomplish.

In a recent work by *Lehman* (7) an entire chapter is devoted to the tremolo, which includes the vibrato. An attempt is made to differentiate between the tremolo and vibrato by making the amount of injury the vocalist suffers in producing them the chief criterion.

"Big voices produced by large, strong organs through which the breath can flow in a broad, powerful stream, are easily disposed to suffer from the tremolo, because the outflow of breath against the vocal cords occurs too immediately. The breath is sent there directly from the diaphragm instead of being driven by the abdominal pressure forward against the chest, the controlling apparatus, from whence it comes, in minimal pressure and under control, is admitted to the vocal cords. Even the strongest vocal cords cannot for any length of time stand the uncontrolled pressure of breath, that is, the direct breath pressure. One must learn to tense them by means of various muscular functions.

"The tremolo can also be produced by the false placement of the larynx which is not always fixed close enough under the nose and chin, and being disunited with e and u by means of y it wabbles around alone.

"Even the vibrato to which full voices are prone, should be nipped in the bud, for gradually the tremolo and later something even worse, is developed from it. Life can be infused into the tone by means of vowel mixing, a way that will do no harm.

"Vibrato is the first stage, and tremolo the second and more hopeless, which shows itself in flat singing on the upper and middle tones of the register."

The following quotation, taken from *Luisa Tetrazzini's* new book, (19) reveals the distinguished singer's attitude toward the tremolo:

"I am not going to attempt a catalogue of all faults which are possible, but name just a few: faulty intonation, faulty phrasing, imperfectly attacking notes, scooping up to notes, digging or arriving at a note from a semitone beneath it, singing out of tune and the tremolo. All of these faults are unforgivable, but the last two are crimes."

Thomas Edison (4) condemns the tremolo and the vibrato, too, by accusing most singers of breaking up their tones into a series of chatterings or tremolos.

"The number of waves varies from two to twelve per second. When at the latter rate, the chatterings can just be heard and are not very objectionable. If this defect could be eliminated, nothing would exceed the beauty of the human voice, but until this is done, there will only be a few singers in a century who can emit pure notes in all registers."

In discussing the beautiful voice of Jean DeRezské, *Herman Klein* (3) points out the following virtues: "His high notes produced with ease and always in perfect tune are magnificent in quality and as resonant as a bell. He sings without a suspicion of the tremolo," etc.

In the last few quotations it is evident that the term tremolo is used interchangeably with the term vibrato. It is unfortunate that voice critics use the two terms synonymously.

There are other voice students who might be quoted as being opposed to the vibrato, but the impression must not be conveyed that the vibrato is tabooed by all voice authorities. The vibrato is not without champions, for many able critics consider it an indispensable part of artistic singing.

"There is a desirable vibration or pulse in every tone which gives it life. This the old Italians called the vibrato; it is quite different from the tremolo. The vibrato is the natural pulse or rhythmic vibration of the tone, and in any attempt to keep the voice steady, this must not be lost; any control which presents this natural vibrato or life-pulse from entering the tone is bad."

This writer (21) has nothing more to say on the subject of the tremolo, except that it is bad. In general, critics who favor the vibrato do so because they feel that a voice without it is "cold, dead, and expressionless."

Rush (13) shows the relationship between the interval in pitch and the emotion conveyed.

"The presence of the tremulous voice is for the purpose of emotional expression. The tremor of the second and wider intervals, expresses states of exultation, mirth, pride, haughtiness, sneer, derision and contempt. The tremor of a semitone expresses suffering, grief, tenderness and supplication."

The vibrato, however, is not the only agency for the expression of emotion, as the following quotations disclose:

"As a general rule, pure tone should be used but there are emotions for the expression of which pure tone seems inadequate, and often inappropriate. Those emotions are more clearly suggested, more strongly impressed on the hearer by a quality more or less breathy, because the actual experiencing of these feelings induces such a quality in speech. In many passages indicative of eagerness, surprise, apprehension, dread and terror this will be found true" (6).

Finally,

"the majority of singers neglect the arduous training which is necessary to develop the will to express. Many pupils do everything their teachers have done, but do not feel; they copy. If they thought of that which they ought to give—if they felt it, they would awaken in themselves the desired means of expressing it, and so would rise to the demands of the author and public. Nothing will assist more the development of the power of expression than a careful study of mimicry and gesture" (20).

It is needless to say that the voice critics and students are more or less puzzled and confused in their thinking on this subject. They differ as to its desirability, nature, value, causes, and appeal. Yet the vibrato appears in the tones of trained vocalists, as this and other investigations conducted at the University of Iowa show. These researches have thrown considerable light on the nature of the vibrato, but the subject is practically unexplored and promises to be a most profitable field for acoustical, physiological and psychological investigation.

This investigation was originally conceived with the purpose of studying the effect of the emotions on the vibrato. Unfortunately, this objective was never realized, because the question of pitch and intensity relationship presented so many problems that required intensive study. However, positive light has been thrown upon a number of art principles and practices by this study.

Every photographic record reveals the fact that a normal tone is one in which both the pitch and intensity factors fluctuate. In trained voices the fluctuations are usually both regular and cyclic, while in untrained voices they are irregular and reveal no progressive tendency. But it must be remembered that both the trained and untrained voice fluctuates. This change in pitch and intensity is normal. No observer was able to produce a tuning-fork-like tone, rigid in pitch and intensity. Yet a few critics were quoted who insisted on steady tones. Voice critics who clamor for the steady tone should analyze the tones of their favorite vocalists with the aid of voice photography to convince themselves that virtuoso vocalists are unable to produce rigid tones.

In closing this section, reference should be made to the bitter controversy which Galli-Curci's initial appearance in London occasioned. It appears that her concert was an unqualified success financially. This was probably due to the advertising campaign which antagonized the music critics and resulted in a conflict between the principal musical magazines of London. Galli-Curci's most vicious critic was *Sorabji*, (**18**) who referred to her concert as " a sorry, sordid, and ridiculous business." One of the chief faults which he points out is her vibrato, of which he speaks satirically:

> "—steadiness of tone, one of the most elementary requisites without which good singing does not even begin to exist, and as though one would have to listen to Galli-Curci to hear steadiness of tone. As who should say, 'Listen to Cortot when he plays a five-finger exercise, and see how he plays all the right notes.'"

This criticism was answered in the *Musical Times* (**11**). The writer, whose name is not revealed, comments on the artist's singing and commends her for the beauty of her " steady, clean vocal tone." Both critics heard the same voice and, yet, are unable to ascertain whether the vibrato was employed; and whether the effect was good or bad because of omission or commission. This episode shows something of the status of the vibrato and also that of musical criticism.

Turning next to the factor of intensity, we observe that this element has been ignored generally; yet it plays a coördinate

part with pitch in making for beauty in singing. If a tone lacks flexibility in intensity, it is deficient in beauty. Just what can be done, in training an individual in intensty control, is a problem which has received little or no attention. Yet voice production involves more than pitch control alone.

In conclusion, it is fair to say that the art of singing is as yet based on no science of singing. The factors that constitute a tone are not clearly understood by critic or teacher. At the present time, voice teachers ignore the basic elements of time and intensity, in their desire to teach the skill required for the control of pitch. Scientific studies of the voice must be encouraged in order to reveal the true nature of the voice to the voice teacher and critic. Unfortunately, the voice teacher is unable to do this for himself, since it requires special equipment and training. Yet the voice teacher is dependent upon this information, for without it he cannot teach voice production.

Summary

1. The vibrato is a periodic phenomenon of three variables; namely, pitch, time, and intensity.
2. The vibrato is produced primarily by trained vocalists, although it is found in the tones of untrained singers; the rate of occurrence being 93 per cent and 27 per cent for trained and untrained, respectively.
3. Placement affects the extent of pitch and intensity fluctuations; the nasal resulting in the smallest and throaty production the largest for both factors.
4. Vowel quality reveals only slight influence on the vibrato.
5. Low tones show a relatively smaller amplitude and a faster rate of pulsation.
6. The vibrato may be increased or diminished by voluntary effort, but it cannot be inhibited or eliminated entirely.
7. Children's voices compare favorably with adult voices in respect to intensity fluctuations, but are relatively more rigid in regard to pitch fluctuations.

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A PHONO-PHOTOGRAPHIC STUDY OF THE STUTTERER'S VOICE AND SPEECH

BY

LEE EDWARD TRAVIS

Nature of the problem; general methods; data for Part I; discussion of Part I; summary and conclusions for Part I; data for Part II; findings for Part II; data for Part III; findings for Part III; general conclusions; references.

Nature of the Problem

There seems to be two aspects of the problem of stuttering:[1] first, nature; and second, cause. In regard to nature one can obtain various descriptions of the malady, or long lists of symptoms, but these tell one little of the psychology, or of the psychopathology, or of the neurology of the matter. The thing that is needed is an explanatory principle or principles.

The second aspect of the problem should immediately arise out of the first. Once having determined the true nature of stuttering or stammering, the question of etiology confronts one. This second part of the problem really contains two subdivisions: first, what originally operated to bring about the condition known as stuttering, and second, what are the recurrent present provoking causes?

All workers in the field are agreed that emotive stimuli are powerful in the production of stuttering. If this is so it should not be so very difficult to apply experimentally stimuli of an emotional nature and then under controlled conditions and by a refined technique determine the effect upon the vocomotor mechanism. Just to determine the effect upon the vocomotor mechanism of the stutterer alone may not mean anything, but to compare these changes with those produced in the non-stutterer under identical circumstances would be very valuable, provided the changes were more marked or different in one case.

[1] This term is intended to include stammering.

This study was begun with the object of determining what effect emotional stimuli had upon the voice of the stutterer and of the non-stutterer and then to compare the effect produced in the case of the former with that produced in the case of the latter.

The data will be considered in three parts: Part I will have to do with the effects of emotional stimuli upon the voice of the stutterer and of the non-stutterer; Part II and Part III will deal with the effect of various situations upon speaking sentences by stutterers and non-stutterers.

General Methods

There is perhaps no better means known for studying the voice than the photographic. There can be only one criticism, namely, that it is too refined for many studies. This criticism, however, is not a valid one as applied to this study, for such a study as this takes account of relatively small changes, especially since these changes are in opposite directions when the two groups, stutterers and non-stutterers, are compared.

The apparatus used for Part I has been described by *Simon* (2) (this volume), hence only sufficient description will be given here to enable the reader to follow the method.

About a six-foot piece of hypersensitive moving picture film is wound on a drum which is the periphery of a ten-pole synchronous motor in circuit with a ten d.v. tuning fork, making it necessary that if the drum revolves at all it revolves at the rate of one revolution per sec. From the standpoint of accuracy it is very essential that this drum revolve at a constant rate of speed. Several tests described by Simon indicate that the synchronous motor does run at a highly constant rate of speed, thus fulfilling this requirement acceptably. A phonelescope is mounted in front of the drum. "Phonelescope" is the trade name of an optical lever. It is built for general use in the projection and photographing of sound waves. The mirror is activated by a very small diaphragm and a beam of light focused upon this movable mirror is reflected to the center of the film. The photographing is done in a dark room, the only illumination coming from a photog-

rapher's safe light hung in a convenient place in order to facilitate putting on and taking off film. After the motor has been started and allowed to pass through its hunting period, the beam of light is focused upon the mirror of the phonelescope and reflected to the center of the film for one revolution of the drum in order to produce a base-line for the wave-curve. This base-line is necessary for reading purposes.

Then the observer sings an " ah " into a horn which is attached to the phonelescope. While he is singing the beam of light is again focused for one revolution of the drum upon the mirror and reflected to the film, a picture of the observer's voice thus being obtained.

The length of each wave is measured in terms of tenths of a mm. As the rate at which the film passes the point of exposure is expressed in terms of mm. per second, this rate can be divided by the wave-length and give a quotient which is the number of times such a wave would occur in a second, or pitch in terms of d.v. This is never actually done, however. An entire film is read and the average wave-length in terms of mm. ascertained. Then this figure is divided into the figure representing the rate per second that the film passes the point of exposure, thus giving the average pitch[1] in terms of d.v.

The wave lengths are measured by means of a measuring microscope, mounted on a vernier graduated scale to read in units of .1 mm.

Pictures of the observer's voice are taken under two conditions. The first condition shall be called the normal or N-condition, while the second shall be called the emotional or E-condition. The picture under the N-condition is always taken prior to the picture of the E-condition. The technique for taking the picture of the N-condition is about as follows: The observer is asked if he has ever seen a picture of the human voice. It is then explained that here is an apparatus for taking such a picture and that a picture of his voice is going to be taken. He is asked to observe the operations of the phonelescope while the experimenter

[1] The average pitch is needed, of course, to determine the variability of pitch.

sings into the horn. Then the observer practices making a sustained tone of a pitch and quality natural to him and of sufficient intensity to produce a fairly large excursion of the beam of light. The film is now wound on the drum while a friendly conversation is carried on with the observer. The desired state of the organism during the procuring of the N-condition picture is one of ease and naturalness. Anything that will contribute to this end is permissible. The observer is asked about his studies, how he likes the university, where he is rooming, if he is interested in athletics, what the outcome of the next football game will be, and so on.

The desired state of the observer for the E-condition picture is that of emotional upheaval. The experimenter begins to bring about such a state by asking such questions as, "Have you ever been terribly frightened?" "Are you nervous?" "Did you ever faint?" "Is your heart in good shape?"—for the obvious purpose of arousing an anticipatory emotional condition. After the film has been placed on the drum and the base-line secured, the observer is required to follow the experimenter into an adjoining room which is very dimly lighted. "Come into this room; I want to test your nerves," is the command. Once in the room, the observer is asked to face a certain direction, close the eyes and permit the experimenter to feel his pulse, it being suggested that this latter is a precautionary measure in case the observer might be subject to fainting or be overcome by the shock. The observer is now asked if he is prepared for a shock and if he thinks he can stand it. Immediately following his reply a .38 caliber revolver is fired about twelve inches in front of his face. He is at once taken to the photographing apparatus where he is asked to firmly grasp two metal clamps. An induced current of considerable strength is then sent through the clamps, giving him an electrical shock which, coming so soon after the pistol shot, is a source of considerable emotional upset. A tone as nearly like the one produced under the N-condition as the observer can make is now photographed.

Both stutterers and non-stutterers have their voices taken under these two conditions in exactly the same way. The voice

waves of the E-condition are compared with those of the N-condition in regard to only one aspect of the wave, namely, variability of wave-length or pitch. Variations in the amplitude and form of the waves were not considered for various technical reasons, the main one being that the phonelescope is not a sufficiently accurate instrument for detecting changes in these two aspects of the wave.

The apparatus[1] used for Part II and Part III is described fully by *Metfessel* (1) (this volume).

Briefly, it differed from that used in Part I in that the film traveled at a much slower rate of speed and the pitch was read by means of a " time-line." The " time-line " is a graphic representation on the film of a 100 d.v. electrically driven tuning fork. The number of waves or fraction of a wave made by the speaker which occur in the distance of .01 sec. are counted. This number when multiplied by 100 gives the pitch in terms of d.v. The time method does away with the necessity of extreme regularity of film passage which the apparatus in Part I possessed. Instead of the observer producing a sustained tone for photographing as in Part I, he speaks complete sentences. These sentences were studied from the standpoint of range of pitch, of time, and of the average pitch at which a sentence was spoken.

For Part II each observer repeated two sentences, first, " This is a fine day," and second, " I am a nut." He was told what the sentence would be several minutes before each picture was taken so that the manner in which the experimenter spoke the sentence would not be very apt to influence the way the observer said it. The instructions were simply to say the sentence any way the

[1] This apparatus was used for Parts II and III instead of that used in Part I because it would permit of several seconds of exposure required for some of the sentences. The apparatus described in Part I permitted a maximum exposure of only one second which time would have been entirely too short for saying the various sentences used in Parts II and III. The apparatus described by Simon was designed primarily to measure variability in successive wave lengths while that described by Metfessel was constructed mainly to study long time fluctuations. As the first part of the experiment had to do with studying single sustained tones Simon's apparatus was preferred but when the second and third parts of the experiment dealt with such factors as range of pitch, time and average pitches of whole sentences Metfessel's technique was the more serviceable.

observer cared to. The pictures of "I am a nut," rather than those of "This is a fine day" spoken when the observer assumed a particular emotional attitude, were compared with the pictures of "This is a fine day" spoken under conditions of ease and naturalness, because one is never sure of the genuineness of an assumed emotion from the standpoint of its effect upon the neuro-muscular organism. Especially is this true when one is dealing with groups of observers having little if any understanding either of the subjective or objective aspects of genuine emotional expression. If the subjects were trained actors or dramatic readers a comparison of the effects of assumed emotional attitudes upon the voice with the findings of a study of the voice under natural emotional conditions might yield legitimate results. This is a study yet to be undertaken. In saying "I am a nut" *O* is not asked to take any particular emotional set. It is supposed that the sentence carries its own emotional stimulus.

For Part III each observer was required to talk in three distinctly different situations. The first situation was designed to produce a condition of mild relaxation. *O* was seated in an ordinary straight backed chair and told to relax as much as possible. Suggestions by means of words such as "Just let go of everything," "Let your legs go perfectly free," "Relax your arms and trunk muscles," and by actually shifting the legs and arms to easy positions were carried on for about five minutes before the picture was taken. At the beginning of the five-minute period of what might be called "progressive relaxation," *O* was told that he would be required to say "The sky is blue" when the experimenter told him to speak. Nothing whatsoever was said as to how the sentence was to be spoken.

The second situation was meant to produce a state of mental flurry. The instructions were about as follows: "Now you can perk up. I want you to work a problem in multiplication and to do it aloud, as I'm going to take a picture of your speech. For instance, if I told you to multiply 25 by 24 you would begin by saying, 4 times 5 is 20, 4 times 2 is 8 and 2 to carry is 10, and so on. Do you understand? Now get ready and speak directly

into the mouth-piece. When I say 'go,' multiply aloud 236 by 27. Begin by saying 7." Just the first sentence, 7 times 6 is 42, was photographed. Of course *O* did not know that the entire multiplication was not to be carried out. Nearly every subject made some such remark as, "I can never do it," or "What if I forget?" Such errors as $7 \times 6 = 36$, or $6 \times 7 = 42$, or 7 6's are 42, occurred several times in both groups of observers. Such facts as these indicate that the desired mental state was secured.

The third situation was designed to produce an emotion of anticipation of a physical injury. Just before the picture was to be taken, an induction coil, a dry cell, a make-key and a leather head-strap carrying two electrodes attached to the terminals of the inductorium were brought to the table near the observer from a concealed place in the room. The head-strap was adjusted so that the two electrodes were pressed firmly against the forehead. The experimenter placed a finger on the make-key and gave instructions about as follows: "You are to say the sentence you spoke for the first picture. (It was always determined that *O* knew he was to say, 'The sky is blue.') When I say speak, you repeat the sentence and the instant you finish I'm going to give you an electrical shock through these two electrodes against your head. The shock will not permanently injure you. Speak directly into the mouth-piece." *O* was actually shocked after the sentence was completed. This would not have been necessary as no further pictures were taken, but in case something happened to make it necessary to take another picture it seemed wiser than not to carry out the threat.

Data for Part I[1]

It will be recalled that Part I deals with the effect of strong emotional stimuli such as a pistol shot and an electrical shock of high potential upon the voice of the stutterer and the non-stutterer during the singing of a tone of constant pitch.

Nineteen stutterers and eighteen non-stutterers furnished

[1]All means and standard deviations in this study were computed with the measures reported at their true values; *i.e.*, in ungrouped or simple series.

seventy-four pictures of the voice for comparisons. The general law can be stated here, that the stutterer has less pitch fluctuations for the E-condition than for the N-condition, while the non-stutterer has more pitch fluctuations for the E-condition than for the N-condition.

This law is borne out by Tables I, II, IV, V, and VI. Table I deals with individual readings on non-stutterers, and Table II with individual readings on stutterers, while Table IV is a summary of Tables I, II, and III. Table III will be discussed later.

TABLE I. *Individual readings on non-stutterers*

Ob-servers	Mean pitch in d.v. N	Mean pitch in d.v. E	Range per cent of a tone N	Range per cent of a tone E	Mean deviation per cent of a tone N	Mean deviation per cent of a tone E	Fluctuation quotient in terms of per cent N	Fluctuation quotient in terms of per cent E
I	165.5	163.7	37.5	76.5	5.65	12.90	.68	1.50
II	106.4	100.6	51.6	52.1	7.06	10.20	.83	1.20
III	178.3	192.9	62.1	20.9	14.60	2.72	1.70	.30
IV	172.4	133.9	24.5	32.9	3.95	4.87	.56	.57
V	136.8	150.7	33.7	34.4	6.25	6.74	.73	1.20
VI	139.9	149.9	33.5	3.4*	6.70	15.20	.80	1.70
VII	111.2	129.4	34.9	94.6	6.74	17.20	.75	1.99
VIII	140.4	125.4	19.1	37.8	3.11	5.50	.37	.62
IX	134.2	138.3	57.5	84.1	7.46	16.20	.88	1.86
X	105.9	175.8	44.4	56.5	6.11	10.20	.72	1.20
XI	113.5	135.5	26.4	42.5	4.42	7.06	.54	.83
XII	145.5	178.7	26.3	38.1	5.20	8.25	.59	.90
XIII	159.5	190.9	49.4	60.0	9.36	13.36	1.11	1.54
XIV	124.7	120.9	41.4	17.1	6.14	3.35	.69	.39
XV	155.5	179.3	38.7	55.7	6.04	9.02	.69	1.33
XVI	155.8	167.1	55.6	73.6	14.30	13.21	1.63	1.50
XVII	152.5	158.4	17.3	34.8	4.55	6.96	.50	.78
XVIII	121.7	127.9	21.4	44.6	3.50	8.06	.40	.95
Average.......			37.5	66.45	6.70	9.50	.78	1.13

* Not per cent of a tone but 3.4 tones.

There is only one thing in the tables that needs explaining. The fluctuation quotient is found by dividing the mean wave-length expressed in terms of mm. into the mean deviation expressed in terms of mm. The purpose of this quotient can be made evident by an example. Let us suppose that A had an average wave-length of 15 mm. and a mean deviation of .3 mm., while B had an average wave-length of 10 mm. and a mean deviation of .3 mm. In both cases the mean deviation is the same, but relatively B's voice was more variable in regard to pitch than A's, as is shown by A's fluctuation quotient being $.3/15 = 2$

per cent and B's fluctuation quotient being $.3/10 = 3$ per cent. In the ultimate analysis the fluctuation quotient is the criterion by which it is determined whether or not an observer's voice has more or less pitch fluctuations for the E-condition than for the N-condition.

The matter of taking a higher or lower tone for the E-condition than for the N-condition gave no differential indication

TABLE II. *Individual readings on stutterers*

Observers	Mean pitch in d.v. N	Mean pitch in d.v. E	Range per cent of a tone N	Range per cent of a tone E	Mean deviation per cent of a tone N	Mean deviation per cent of a tone E	Fluctuation quotient in terms of per cent N	Fluctuation quotient in terms of per cent E
A	105.5	117.1	43.7	30.8	7.2	4.4	.86	.55
B	149.0	152.0	61.3	32.3	10.3	6.0	1.15	.70
C	160.3	174.9	37.7	10.8	10.9	7.5	1.28	.86
D	162.7	177.0	56.7	36.7	12.3	5.9	1.43	.70
E	178.7	164.4	43.4	23.1	6.6	5.2	.78	.60
F	142.2	139.0	31.4	23.8	6.7	3.4	.75	.41
G	187.3	180.0	27.3	26.5	6.2	6.0	.69	.66
H	283.6	285.3	93.4	29.7	15.7	4.0	1.77	.47
I	122.2	125.8	26.4	30.2	5.3	4.8	.61	.57
J	140.4	134.7	30.8	23.8	5.0	3.6	.57	.43
K	251.3	308.6	37.0	33.7	6.1	5.7	.68	.65
L	149.7	161.7	49.4	28.2	7.5	2.0	.86	.24
M	135.8	134.7	93.3	30.0	15.6	4.4	1.73	.49
N	138.2	145.0	39.6	21.9	7.4	5.4	.85	.59
O	148.2	178.3	45.9	30.9	6.8	4.8	.82	.57
P	162.7	165.7	41.0	35.2	6.1	4.1	.72	.47
Q	129.5	122.9	56.0	22.1	7.1	4.8	.83	.55
R	272.2	247.2	47.5	18.0	5.9	2.4	.69	.27
S	167.6	184.2	43.4	13.2	6.1	3.6	.69	.41
Average			47.6	26.3	8.1	4.6	.93	.54

between the stutterers and non-stutterers, as a relatively equal number of each group took a higher tone for E than for N.

Range, mean deviation, and fluctuation quotient are different ways of looking at variability. Hence it is to be expected that a very close agreement would exist between them in expressing comparative variability between the two groups, and such is the case as is shown in Table IV. For the 18 non-stutterers shown in Table I, and again in Table IV, 16 had a greater singing range, 16 had a greater mean variation of pitch, and 15 had a greater fluctuation quotient for the E-condition than for the N-condition. For the stutterers shown in Table II, and again in Table IV, 18 had a smaller singing range, 19 a smaller mean deviation in pitch, and 19 a smaller fluctuation quotient for the E-condition than for

the N-condition. Thus the variability in pitch of the voices of the two groups behaved exactly the opposite under the effects of an emotional upset, it being less for the stutterers and more for the non-stutterers.

The first point to be thought of here is that possibly these findings are purely fortuitous. With only nineteen cases in one group and eighteen in the other, possibly such differences as were discovered would occur just as readily according to the laws of pure chance. There are two possibilities in regard to changes in variability of pitch under the emotional condition. Either there will be more variation or there will be less. If no factors other than chance are operating, how often would every one of the nineteen stutterers have less variation in pitch after the administration of the emotional stimuli than under normal circumstances and fifteen of the eighteen non-stutterers have more variation in pitch after the administration of the emotional stimuli than under normal circumstances?

Let $p =$ change $+$, (greater variability)
and $q =$ change $-$, (less variability).
Now $(p + q)^n =$ chance probability
where $p + q = 1$ and $p = q$.
Therefore $p = \frac{1}{2} = q = \frac{1}{2}$ and $(\frac{1}{2} + \frac{1}{2})^n =$ chance probability.

Since in the case of the stutterers it is 19 against 0, and the first term of the chance probability equation would be the same as the last, $(1/2)^{19}$ will give the correct answer, which is 524,288. Hence we can say that if no factors other than chance were operating we could expect the results obtained with stutterers to occur once in 524,288 times.

The same formula can be applied to the results obtained from non-stutterers. Here, however, it is necessary to take the fourth term of the binomial equation, since there are 15 against 3. This fourth term is

$$\frac{n(n-1)\,(n-2)}{1 \times 2 \times 3}(1/2)^{n-3}(1/2)^3. \;\; . \;\; . \;\; .$$

By substitution we get $\dfrac{816}{262{,}144}$, which means that if no factors

other than chance were operating to cause fifteen out of eighteen non-stutterers to have more variations of pitch for the E-condition than for the N-condition it would happen only once in 321 times.

Table III shows the findings on five former stutterers which are divided into two groups, recovered stutterers and cured stutterers. By recovered stutterers is meant those stutterers who

TABLE III. *Individual readings on former stutterers*

Observers	Mean pitch in d.v. N	Mean pitch in d.v. E	Range per cent of a tone N	Range per cent of a tone E	Mean deviation per cent of a tone N	Mean deviation per cent of a tone E	Fluctuation quotient in terms of per cent N	Fluctuation quotient in terms of per cent E
I R	170.2	147.0	41.25	22.69	10.60	4.13	1.250	.469
II R	157.1	147.1	17.08	10.66	4.27	2.55	.484	.289
III R	153.7	134.0	21.85	41.92	4.16	9.62	.480	1.340
IV R	155.6	148.4	39.49	38.50	5.62	9.28	.642	1.040
V R	152.5	153.6	26.80	44.21	4.38	9.27	.411	1.074

ceased to stutter without any kind of treatment whatsoever while by cured stutterers is meant those stutterers who were treated and subsequently recovered. The number of cases of former stutterers here reported is very small but the findings are extremely interesting. Table IV shows that the voices of the recovered stutterers behave under the E-condition exactly as those of the non-stutterers while the voices of the cured stutterers under the E-condition behave exactly like those of the stutterers. This fact raises several interesting questions which will be discussed later.

TABLE IV. *Summary of Tables I, II, and III*

Group	Number of observers taking a higher tone for E	Number of observers taking a lower tone for E	Number of observers having a greater range for E	Number of observers having a smaller range for E	Number of observers having a greater mean deviation for E	Number of observers having a smaller mean deviation for E	Number of observers having a greater fluctuation quotient for E	Number of observers having a smaller fluctuation quotient for E	Total number of cases
Non-stutterers........	13	5	16	2	16	2	15	3	18
Stutterers............	12	7	1	18	0	19	0	19	19
Recovered stutterers ..	1	2	2	1	3	0	3	0	3
Cured stutterers	0	2	0	2	0	2	0	2	2

Table V gives the average range, the average of the mean deviations and the average fluctuation quotient for the two groups under the two conditions. There are two ways of looking at the table. The first way is to see whether or not there is a significant difference between the average range of the non-stutterer for the N-condition and the average range of the stutterer for the N-condition; between the average range of the non-stutterer for the E-condition and the average range of the stutterer for the E-condition, and so on in like fashion for the average of the mean deviations and the average fluctuation quotient. Below each vertical pair of figures is given the difference between the two numbers and the probable error of the difference. There seems to be significant difference in every case except two where the difference in each case is only twice its probable error. When this 2 to 1 relationship holds true between a difference and its probable error the chances are 9 to 1 that there is a real difference.

TABLE V. *Compilation of averages*

Observers	Average range per cent of a tone		Average of the mean deviations per cent of a tone		Average fluctuation quotient in terms of per cent	
	N	E	N	E	N	E
Non-stutterers....	37.5	66.45	6.7	9.5	.78	1.13
Stutterers........	47.6	26.36	8.1	4.6	.93	.54
	D=10.1	D=40.09	D=1.4	D=4.9	D=.15	D=.59
	±3.5	±11.0	±.69	±.69	±.075	±.07

TABLE VI. *Rank from standpoint of greatest range, mean, and fluctuation*

Individual Observer	Greatest range per cent of a tone		Greatest mean deviation per cent of a tone		Greatest fluctuation quotient in terms of per cent	
	N	E	N	E	N	E
Non-stutterer.....	62.1	340.0	14.6	17.2	1.70	1.99
Stutterer.........	93.4	36.7	15.7	7.5	1.77	.86

TABLE VII. *Rank from standpoint of smallest range, mean, and fluctuation*

Individual Observer	Smallest range per cent of a tone		Smallest mean deviation per cent of a tone		Smallest fluctuation quotient in terms of per cent	
	N	E	N	E	N	E
Non-stutterer.....	17.3	17.1	3.11	2.72	.37	.30
Stutterer.........	26.4	10.8	5.00	2.00	.57	.24

The other use to make of Table V is to compare the average range, the average of the mean deviation, and the average fluctuation quotient for the N-condition with those of the E-condition in the case of each of the two groups. That is, compare the average range of the stutterer for the N-condition with the average range of the stutterer for the E-condition and so on.

Below is given a summarized statement of these comparisons.

Non-stutterers

For Range, $E-N=66.45-37.5=28.95\pm11.23$
For M. D., $E-N=9.5-6.7=2.8\pm.82$
For F. Q., $E-N=1.13-.78=.33\pm.07$

Stutterers

For Range, $N-E=47.6-26.36=21.24\pm3.05$
For M. D., $N-E=8.1-4.6=3.5\pm.52$
For F. Q., $N-E=.93-.54=.39\pm.055$

It is seen that in every instance there is a significant difference which emphasizes very clearly the facts brought out in Tables I, II, and IV concerning the decreased variability in pitch for

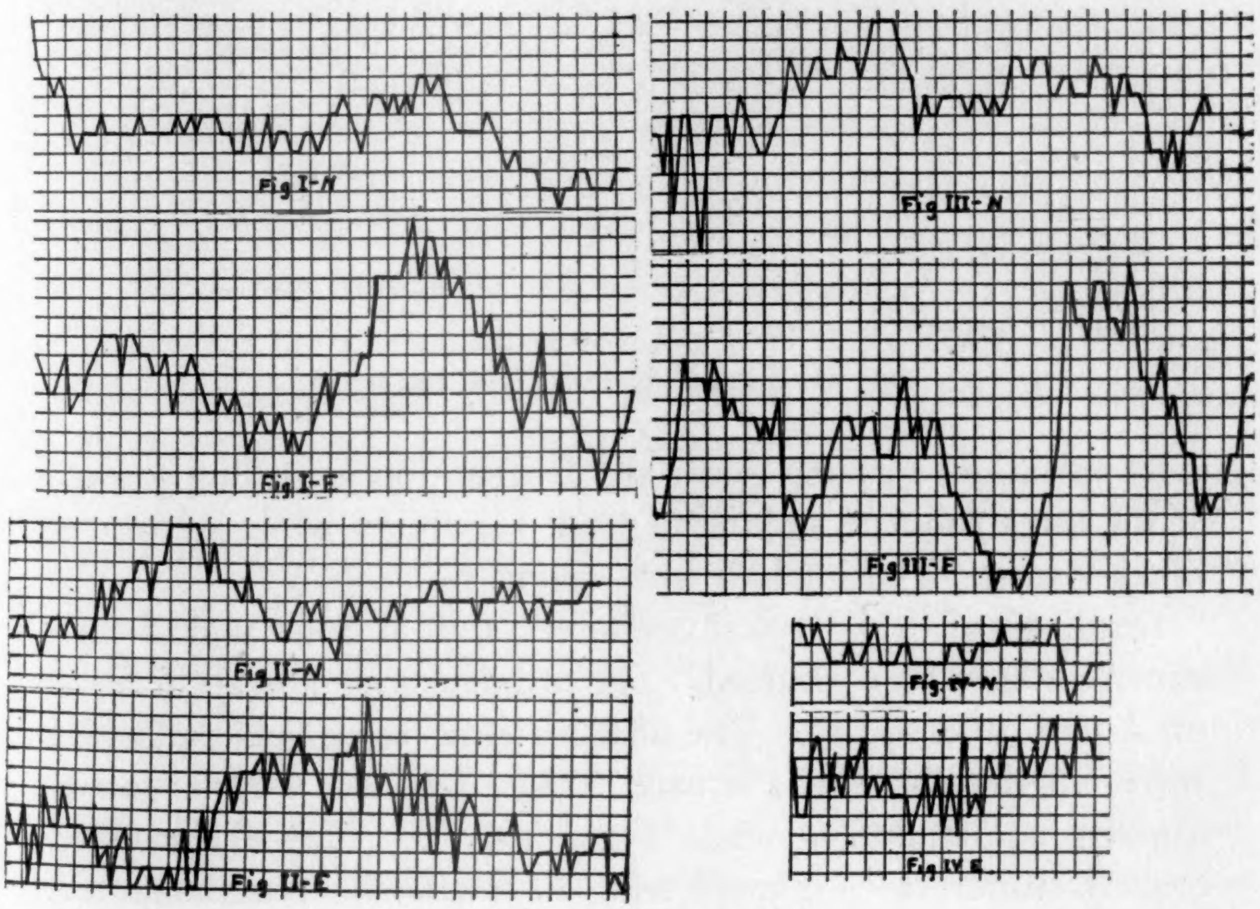


Plate I, Figs. I–N to IV–E inclusive

the stutterers under the E-condition and the increased variability in pitch for non-stutterers under the E-condition.

Tables VI and VII show that from the standpoint of figures on individuals as given in Tables I and II, the stutterer ranks first for most variation in pitch under the N-condition, according to range, mean deviation and fluctuation quotient, while a non-stutterer stands lowest; and that a non-stutterer ranks first for

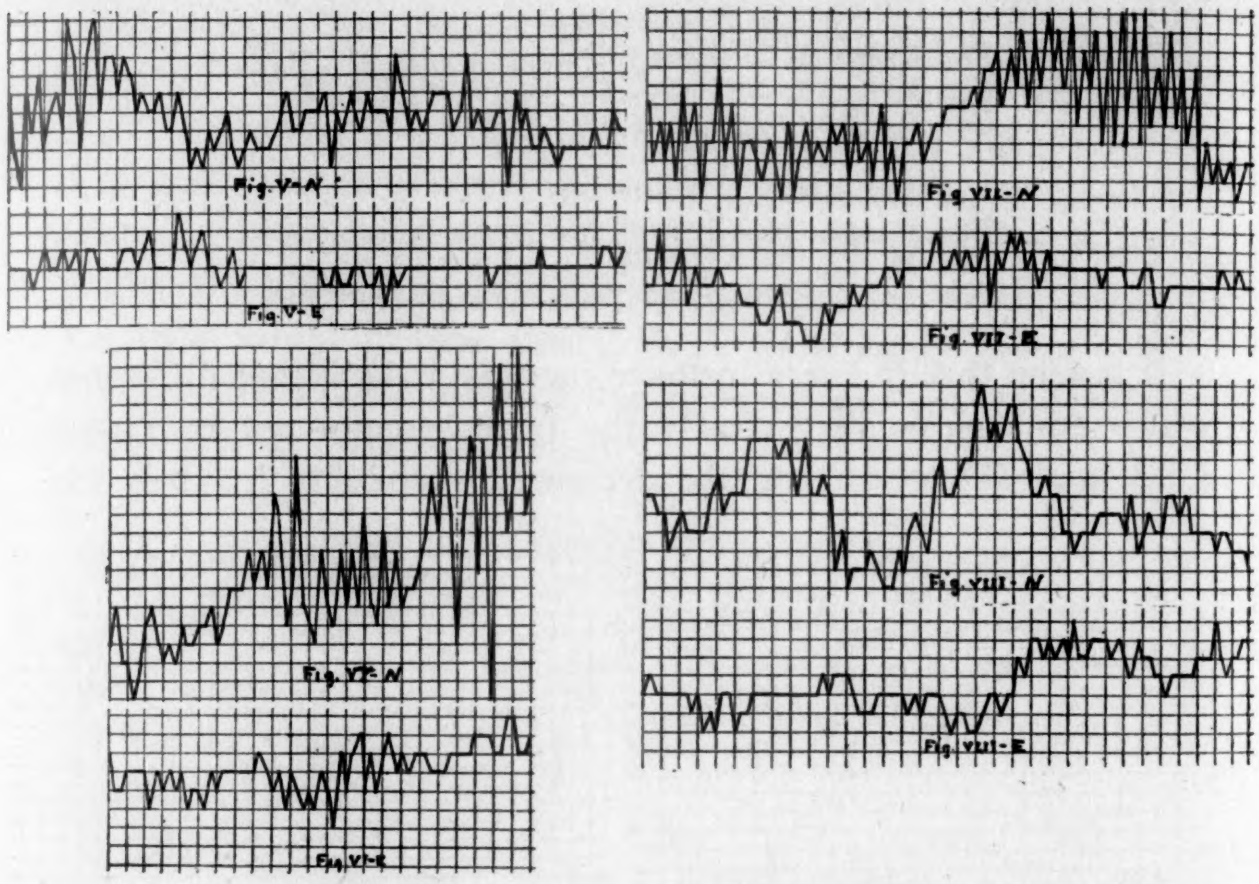


Plate II, Figs. V–N to VIII–E inclusive

most variations in pitch under the E-condition according to each of the three ways of looking at pitch variability while a stutterer ranks lowest. These tables lend weight to Table V.

Readings of four typical stutterers and of four typical non-stutterers have been graphed. The ordinate scale is read in terms of .1 mm. to a square. The abscissa scale represents successive wave lengths, three to a square. Figs. I-N to IV-E, inclusive, concern non-stutterers while Figs. V-N to VIII-E, inclusive, concern stutterers. Figures having an N after the roman numeral refer always to the voice under the N-condition while figures hav-

ing an E after the roman numeral refer always to the voice under the E-condition. Fig. I-N, for example, gives the wave-length readings of a non-stutterer's voice under the N-condition while Fig. I-E gives the wave-length readings of the same non-stutterer's voice under the E-condition, and so on.

These graphs show in a very clear manner, the difference in effect of the emotional situation upon the voices of the two types of observers.

Discussion of Part I

The data thus show in general that stutterers have less variability of pitch after an emotional shock than under normal circumstances while non-stutterers have more variability of pitch after an emotional upset than under normal conditions.

The vocal cords may be either relaxed or tightened, and lengthened or shortened or both; beyond this it is scarcely understandable how they might be modified so as to be effective in the production of sounds of different pitch. These modifications of the cords are brought about mainly by the antagonistic action of two sets of muscles, the crico-thyroid and the thyro-arytaenoid. The crico-thyroid is attached to the anterior arc of the cricoid cartilage and to the inferior cornu of the thyroid cartilage.

When this muscle contracts the anterior part of the cricoid is drawn up the posterior part down, and the arytaenoid cartilage, resting on the upper part of the signet of the cricoid, backward, so that the vocal bands are made longer and more tense.

The thyro-arytaenoid muscle extends from the anterior-external surface of the arytaenoid cartilage to the angle of the ala of the thyroid. The action of this muscle is to loosen the vocal cords by reducing the distance between the arytaenoid and the angle of the ala.

Although the crico-thyroid and the thyro-arytaenoid muscles are antagonistic and either may act very much alone, they coöperate in proper muscular balance to steady their action, for in movements so intricate and complex, as are those of voice-

production, muscular coöperation and muscular balance are better expressions of the processes involved.

Now a certain pitch is maintained by a proper balance between the two sets of vocal muscles, and variations in pitch occur when for some reason or other this proper balance is disturbed and one or the other of the two pairs of muscles changes, or is caused to change, its relative tenseness or state of relaxation. When the non-stutterer is subjected to the shot and the electrical shock, the muscular balance responsible for the maintenance of a tone of a certain pitch is disturbed so that, as compared with the relatively constant pitch of the voice under normal circumstances, many and comparatively great variations are brought about. This is what the average worker in the field of emotions would have anticipated and he would have expected further that stutterers would show under the conditions of the emotional situation a still greater upset in muscular balance which would bring about in turn still greater changes in pitch. Just the opposite, however, actually occurred. When the stutterer is exposed to the emotional stimuli of the experiment, the muscular balance necessary for voice production seems to be rigidly maintained so that variations in pitch are markedly reduced both as to number and size. Instead of muscular lability after an emotional shock there is muscular fixation.[1]

The production of this muscular fixation by the emotional upheaval would seem then to be the phenomenon responsible for the unexpected results. If this is so, stuttering consists primarily not of muscular lability as is most commonly supposed, but of muscular fixation and rigidity. Why the emotions produce the muscular fixation in the case of the stutterer is open for further

[1] It is not to be inferred from this discussion that *lack* of variation in pitch is characteristic of the normal tone, or is a criterion of the normal functioning of the voice-producing mechanism. Seashore and his students have determined that voice waves of a sustained tone not only vary in length but that they vary in a regular recurring order. This phenomenon has been called the "vibrato." Thus a certain amount of disturbance of the muscular balance which would be necessary to maintain a tone of absolutely constant pitch is the normal state. If, however, the variations in pitch or wave length become too marked or are practically eliminated, then the normal condition is no longer existent.

investigation and it is hoped that light can be thrown upon it in the near future.

A few words in closing should be said in regard to the recovered and the cured stutterers. The cured stutterer is suffering mainly from a relatively great emotional lability and is always fundamentally a stutterer. The problem of the stutterer who recovers without any sort of outside therapeutic aid is not mainly one of the emotions but probably one of a relatively great imitative faculty or of great susceptibility to suggestion. This differentiation may border on artificiality but it is the best that can be done on limited data.

Summary and Conclusions for Part I [1]

1. Under normal conditions the stutterer seems to have more variation in pitch than the non-stutterer.

2. After being subjected to the report of the pistol shot and an electrical shock, the stutterer has less pitch fluctuation than under normal circumstances, while the non-stutterer has more.

3. Under emotional conditions the stutterer has less pitch variability than the non-stutterer.

4. The two stutterers who had been treated and subsequently recovered behaved in regard to pitch fluctuation after an emotional upset like the stutterers while the three stutterers who recovered without treatment behaved like the non-stutterers in regard to pitch variability after an emotional upset.

5. The phenomenon responsible for the marked eradication of variations in pitch in the case of the stutterer after the administration of the emotional stimuli seems to be muscular fixation.

6. The physiological effects of the shot and the shock in the case of the stutterer probably bear some causal relation to the muscular fixation.

7. Why the physiological effects should cause the muscular fixation phenomenon in the case of the stutterer and greater flexibility in the vocal-musculature of the non-stutterer involves too many unsolved problems to warrant an answer at this time.

[1] It should be borne in mind that these conclusions refer to a single sustained tone.

Data for Part II

Part II was a comparative photographic study of "This is a fine day" and "I am a nut" when spoken by the two groups, stutterers and non-stutterers. The study involved the factors of

TABLE VIII. *Individual readings on non-stutterers*

	I		II	
Observer	Range	Time	Range	Time
A	7.8	1.75	4.5	.83
B	7.5	2.05	3.5	.83
C	7.9	2.15	1.6	1.15
D	5.5	1.60	...	...
E	7.6	1.25	3.1	.90
F	5.9	1.55	2.7	1.06
G	3.2	1.55	...	...
H	5.3	1.35	4.9	.73
I	5.9	1.45	2.8	.88
J	4.2	1.35	3.5	.89
K	3.3	1.82	3.9	1.45
L	4.2	1.73	3.5	1.28
M	5.0	1.85	1.5	1.40
N	6.4	1.45	2.5	.93
O	3.2	1.25	2.9	.75
P	6.0	1.40	2.1	1.24
Q	4.7	2.30	2.5	1.21
R	3.5	1.59	2.3	1.26
S	5.6	1.21	3.2	.95
T	5.5	1.44	2.6	.97
Mean	5.4	1.60	2.9	1.04
S. D.	1.5	.315	.87	.216

TABLE IX. *Individual readings on stutterers*

	I		II	
Observer	Range	Time	Range	Time
A	3.1	1.80	3.6	1.39
B	3.8	1.14	7.4	1.00
C	2.8	1.38	5.5	1.30
D	3.7	1.48	4.3	1.22
E	2.3	1.15	4.0	1.10
F	4.4	2.30	6.4	1.35
G	2.3	1.43	5.5	1.27
H	3.6	2.05	6.7	1.28
I	2.1	2.15	...	....
J	2.4	1.31	2.6	.80
K	3.3	1.75	4.4	1.29
L	3.1	1.60	3.5	1.05
M	3.1	1.47	5.3	1.10
N	3.1	....	5.3	1.27
O	2.9	1.34	3.8	1.04
P	2.3	2.50	7.7	1.77
Q	4.0	1.25	4.1	.87
R	4.1	1.68	5.5	1.08
S	2.2	2.20	2.9	1.50
T	5.0	1.90	5.5	1.19
Mean	3.2	1.66	4.9	1.20
S. D.	.79	.398	1.4	.217

range of pitch, duration of time for speaking the sentences and the average pitch at which the sentences were spoken. For sake of brevity in the tables, the situation involving the saying of "This is a fine day" will be indicated by I while the saying of "I am a nut" will be indicated by II. Range of pitch is given in

TABLE X. *Comparison of I and II for range only**

Group	No. having greater range for I	No. having greater range for II	No. having same range for I & II
Non-stutterers.......	17**	1	0
Stutterers...........	0	19**	0

* The two sentences cannot be compared in regard to time as one is longer than the other.
** Two non-stutterers and one stutterer had no pictures taken for II.

TABLE XI. *Mean range, mean time, and standard deviations*

	I				II			
Group	Mean range	S.D. of range	Mean time	S.D. of time	Mean range	S.D. of range	Mean time	S.D. of time
Non-stutterers..	5.4	1.50	1.60	.316	2.9	.87	1.04	.217
Stutterers...	3.2	.79	1.66	.398	4.9	1.40	1.20	.218

TABLE XII. *Pitches of whole sentences for non-stutterers*

Observer	I	II
A..	170	141
B..	127	130
C..	143	118
D..	141	...
*..	...	...
F..	165	127
G..	170	...
*..	...	...
I..	156	136
J..	115	122
K..	113	113
L..	144	126
M..	140	142
N..	164	174
O..	127	136
P..	151	174
Q..	151	163
R..	122	119
S..	124	113
T..	143	130
Mean.....................................	142	135
S. D.....................................	17.78	19.02

* Pitches for E and H are not given.

terms of tones, time in terms of seconds and average pitch of a sentence in terms of d.v. There were 20 observers in each group.

TABLE XIII. *Pitches of whole sentences for stutterers*

Observer	I	II
A	157	166
B	192	143
C	162	142
D	177	157
E	124	158
F	121	143
G	147	131
H	175	172
I	122	...
J	135	169
K	119	102
L	155	134
M	116	110
*	...	...
O	121	116
P	128	111
Q	139	135
R	110	110
S	91	92
T	149	129
Mean	139	134
S. D.	25.33	23.39

* Pitch for N is not given.

Tables VIII, IX, X, XII, and XIII are self-explanatory. In studying Table XI, the following substitutions were made:

For mean range of non-stutterers.
Let I = N R I
II = N R II

For mean range of stutterers.
Let I = S R I
II = S R II

For mean time of non-stutterers.
Let I = N T I
II = N T II

For mean time of stutterers.
Let I = S T I
II = S T II

For S. D. dist. for range* of non-stutterers.
Let I = N D R I
II = N D R II

For S. D. dist. for range of stutterers.
Let I = S D R I
II = S D R II

* Differences in S. D.'s dist. for time of the two groups under the two conditions are not worth noting.

The following ten equations were derived:

1.	NRI — SRI	$= 5.4 - 3.2 = 2.2 \pm .28$		O.D.* $= 7.9 \times \text{P.E.}_{\text{diff}}$
2.	NRI — NRII	$= 5.4 - 2.9 = 2.5 \pm .29$		O.D. $= 8.6 \times \text{P.E.}_{\text{diff}}$
3.	SRII — SRI	$= 4.9 - 3.2 = 1.7 \pm .26$		O.D. $= 6.5 \times \text{P.E.}_{\text{diff}}$
4.	SRII — NRII	$= 4.9 - 2.9 = 2.0 \pm .27$		O.D. $= 7.4 \times \text{P.E.}_{\text{diff}}$
5.	STI — NTI	$= 1.66 - 1.60 = .06 \pm .0778$		....
6.	STII — NTII	$= 1.20 - 1.04 = .16 \pm .048$		O.D. $= 3.3 \times \text{P.E.}_{\text{diff}}$
7.	NDRI — NDRII	$= 1.50 - .87 = .63 \pm .18$		O.D. $= 3.5 \times \text{P.E.}_{\text{diff}}$
8.	SDRII — SDRI	$= 1.40 - .79 = .61 \pm .15$		O.D. $= 4.1 \times \text{P.E.}_{\text{diff}}$
9.	NDRI — SDRI	$= 1.50 - .79 = .71 \pm .18$		O.D. $= 4.0 \times \text{P.E.}_{\text{diff}}$
10.	SDRII — NDRII	$= 1.40 - .87 = .53 \pm .15$		O.D. $= 3.5 \times \text{P.E.}_{\text{diff}}$

* O.D. = Observed difference.

TABLE XIV. *Means and S.D.'s for pitches of whole sentences*

	I		II	
Group	Mean	S.D.	Mean	S.D.
Non-stutterers	142	17.78	135	19.02
Stutterers	139	25.33	134	23.39

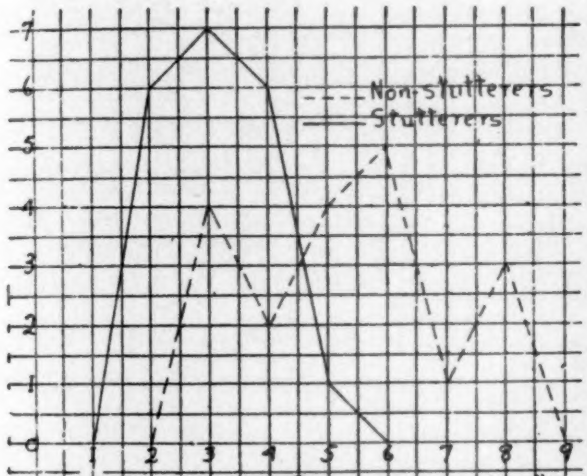


Fig IX. Distribution of "This is a fine day"

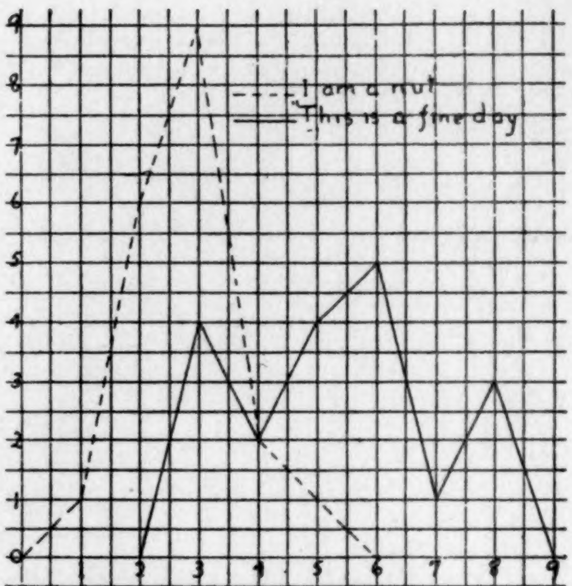


Fig XI. Distribution of Non-stutterers

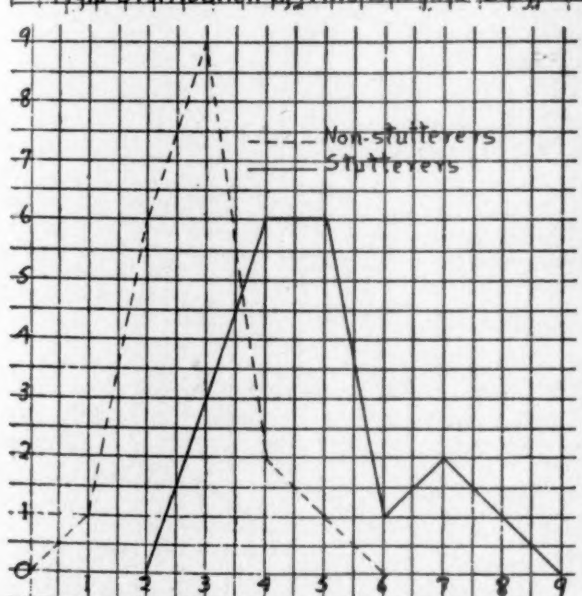


Fig X. Distribution of "I am a nut"

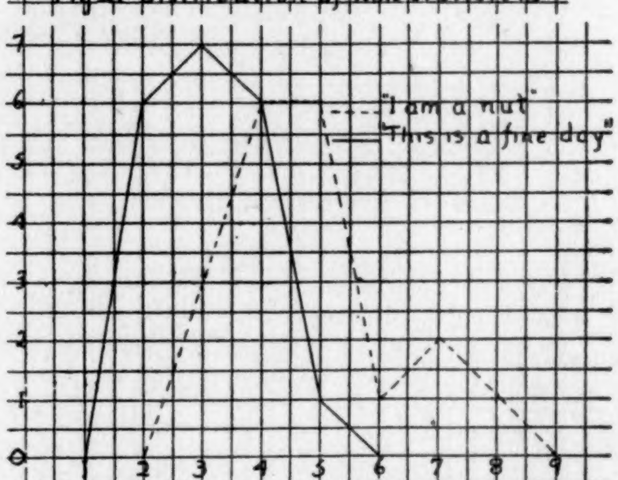


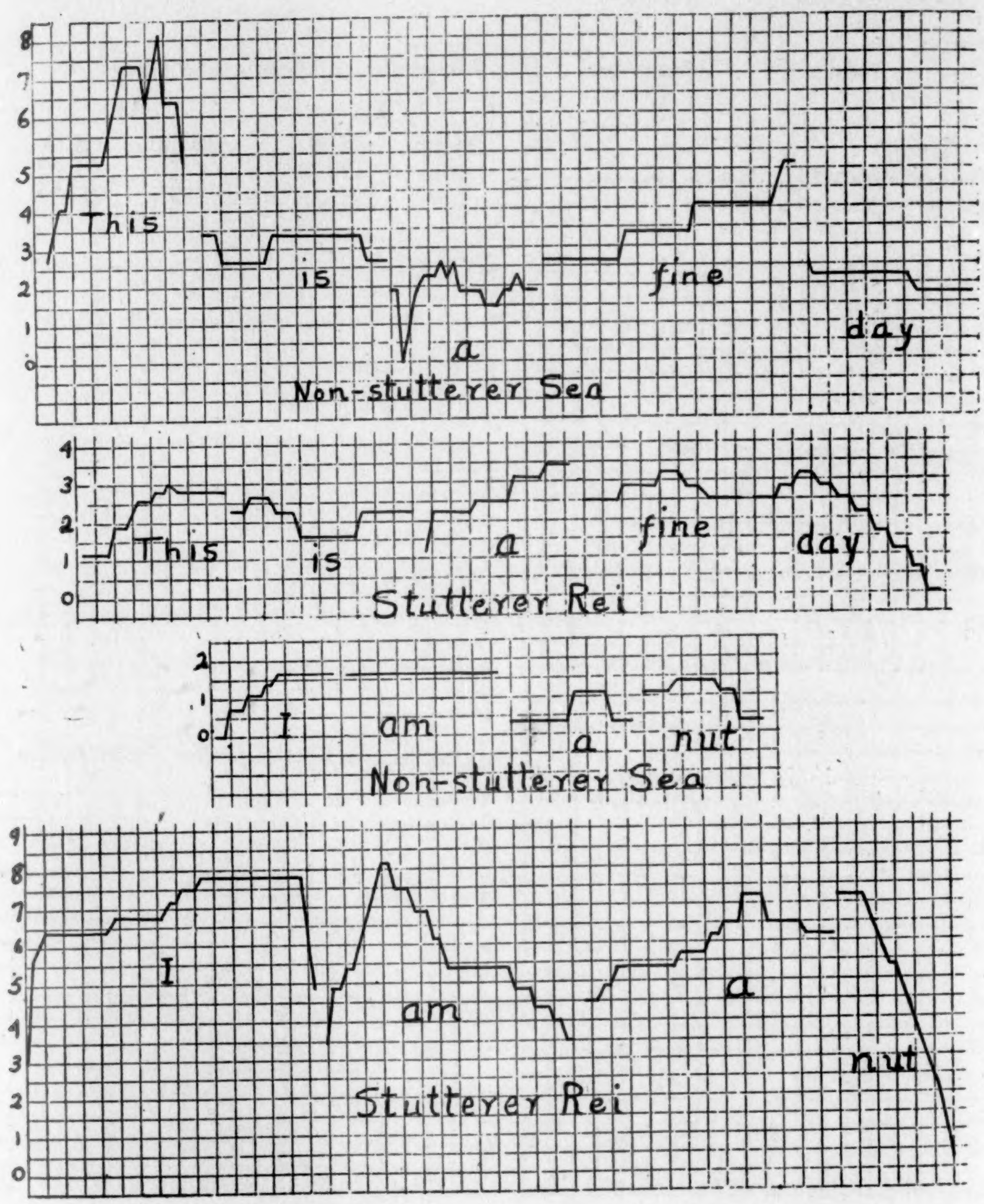
Fig XII. Distribution of Stutterers

For Table XIV the following substitutions were made:

For S.D. of non-stutterers*
Let $I = NDPI$
$II = NDPII$

For S.D. of stutterers
Let $I = SDPI$
$II = SDPII$

* No other substitutions were necessary as the differences between means were not worth considering.



Now the following two equations were considered:

1. $SDPI - NDPI = 25.33 - 17.78 = 7.55 \pm 3.41$
2. $SDPII - NDPII = 23.39 - 19.02 = 4.37 \pm 3.46$

A study of the tables will show that in several instances no differences between means or standard deviations existed. Where this fact was very evident no cognizance of any sort was taken of the differences. In those instances where there turned out to be no real differences between the various means and the various standard deviations, the observed differences with their probable errors were given nevertheless, in order to lend completeness to the study. This holds true for Part III as well.

Four distribution curves are included. The ordinate scales give the number of cases while the abscissa scales give the number of tones.

Readings for each sentence of a typical stutterer and typical non-stutterer have been graphed. Each square in a vertical direction is a half tone while each square in a horizontal direction is .03 of a second. These graphs show two things: first, that the stutterer as compared with the non-stutterer has less range in pitch when speaking "This is a fine day" and more range in pitch when speaking "I am a nut"; and second that the stutterer consumes more time than the non-stutterer in saying, "I am a nut."

Statement of Findings for Part II [1]

A study of all data for Part II warrants the listing of the following ten findings.[2]

1. Stutterers have a smaller range in pitch than non-stutterers when each group makes an habitual statement.

[1] If all speech were divided into two kinds, propositional and repetitional, that used for this study would be a form of repetitional speech, possibly auditory repetitional. Therefore, any statement of findings will have to bear this fact constantly in mind. A study concerning propositional speech is going to be carried on this coming year.

[2] In order to save an undue amount of repetition it seems wise to let a word or two describe from the standpoint of stimulus, each of the two sentences. Thus, "This is a fine day" shall be called "habitual statement," and "I am a nut" shall be known as "belittlement."

2. Stutterers have a greater range in pitch than non-stutterers when each group makes a statement signifying belittlement.

3. Non-stutterers have a greater speaking range for an habitual statement than for a statement of belittlement.

4. Stutterers have a greater speaking range for a statement of belittlement than for an habitual statement.

5. From the standpoint of range, non-stutterers as a group have a greater variability when they make an habitual statement than when they make a statement of belittlement. That is, the speaking of " I am a nut " confines the ranges of pitch for the non-stutterers within rather narrow limits.

6. Stutterers as a group, have a greater variability in regard to range in pitch when they make a statement of belittlement than when they make an habitual statement. That is, the speaking of " I am a nut " causes a greater variability of pitch range among a group of stutterers than the speaking of " This is a fine day."

7. Non-stutterers have a greater dispersion in regard to range for an habitual statement than stutterers.

8. Stutterers have a greater dispersion in regard to range for a statement of belittlement than non-stutterers.

9. It takes a stutterer longer than a non-stutterer to make a statement of belittlement. There is no difference in the length of time it takes the two to make an habitual statement.

10. No real differences between stutterers and non-stutterers were found in regard to the average pitch at which a sentence was spoken or in regard to variability of average pitches at which sentences were spoken.

Data for Part III

For brevity's sake in the tables, the saying " The sky is blue " under relaxed conditions is designated by I, " Seven times six is forty-two " by II, and " The sky is blue," under conditions of expecting a shock, by III.

TABLE XV. *Individual readings on non-stutterers*

Observer	I Range	I Time	II Range	II Time	III Range	III Time
I	3.8	2.42	3.9	2.35	2.8	1.70
II	5.0	1.37	2.8	1.65	4.4	1.10
III	3.5	1.23	2.8	2.60	1.0	.95
IV	4.6	1.35	4.8	2.55	2.8	1.15
V	2.5	2.10	2.8	2.54	1.0	1.45
VI	5.5	1.15	3.2	2.85	3.1	1.17
VII	7.0	1.45	1.7	2.00	3.5	1.15
VIII	3.5	1.70	2.0	2.50	1.2	1.35
IX	2.0	1.45	1.2	2.80	0.8	1.20
X	1.5	1.50	0.8	3.00	0.8	.90
XI	3.0	1.50	2.2	1.70	1.2	1.08
XII	4.9	1.20	2.6	1.78	1.2	1.10
XIII	5.0	1.42	3.2	2.75	3.5	.76
XIV	3.0	1.45	1.7	3.20	1.5	1.10
XV	3.0	1.45	1.5	2.25	1.6	1.37
XVI	3.6	1.55	2.2	2.00	3.0	1.30
XVII	4.9	1.25	3.5	2.40	2.2	1.05
XVIII	4.6	1.70	5.0	2.15	2.2	1.30
XIX	3.8	1.37	1.8	2.20	3.2	1.15
Mean	3.9	1.50	2.6	2.38	2.16	1.22
S.D.	1.29	.298	1.1	.42	1.07	.20

TABLE XVI. *Individual readings on stutterers*

Observer	I Range	I Time	II Range	II Time	III Range	III Time
A	2.3	1.70	3.5	1.85	6.6	1.15
B	2.0	....	4.0	2.38	4.6	1.65
C	3.5	1.62	3.6	2.20	2.8	....
D	1.9	1.28	2.7	2.20	2.5	.95
E	2.0	1.63	3.2	2.30	4.1	1.19
F	1.0	1.70	2.5	2.00	5.1	1.67
G	2.0	1.80	1.9	1.70	5.2	1.00
H	3.5	2.10	4.7	2.45	2.5	1.10
I	4.7	1.63	3.5	2.60	6.8	1.55
J	2.2	1.30	4.7	1.15	5.1	....
K	1.5	1.90	3.5	1.90	3.3	1.05
L	4.0	1.40	3.5	2.05	5.7	1.45
M	2.5	1.20	3.2	2.62	4.6	1.08
N	0.5	1.20	2.9	1.60	3.0	1.05
O	2.3	1.30	3.5	1.85	4.8	1.15
P	3.5	1.60	3.5	2.05	9.2	1.25
Q	4.5	1.68	3.3	2.62	5.1	1.30
R	1.0	1.77	4.2	2.53	4.1	1.53
S	2.8	1.73	3.0	2.35	2.9	1.42
Mean	2.5	1.58	3.4	2.13	4.6	1.27
S. D.	1.17	.246	.67	.382	1.59	.227

TABLE XVII. *Comparison of I and II for range only**

Group	No. having greater mean range for I	No. having greater mean range for II	No. having same mean range for I and II
Non-stutterers	15	4	0
Stutterers	5	13	1

* II cannot be compared from the standpoint of time with the other two conditions as different sentences were used.

TABLE XVIII. *Camparison of I and III*

	No. having greater range for I	No. having greater range for III	No. taking longer time for I	No. taking longer time for III
Non-stutterers.......	19	0	18	1
Stutterers...........	1	18	15*	1

* Time was not read for three stutterers.

TABLE XIX. *Comparison of II and III for range only*

	No. having greater range for II	No. having greater range for III	No. having same range for II and III
Non-stutterers...........	12	6	1
Stutterers................	6	13	0

TABLE XX. *Comparison of all three conditions**

	No. having greatest range for I	No. having greatest range for II	No. having greatest range for III	No. having longest time for I	No. having longest time for III
Non-stutterers....	15	4	0	18	1
Stutterers........	0	6	13	15†	1

* Cannot compare time of II with I and III.
† No time read for three stutterers.

TABLE XXI. *Group mean for range and time*

	I		II		III	
	Range	Time	Range	Time	Range	Time
Non-stutterers....	3.93	1.50	2.61	2.38	2.16	1.22
Stutterers........	2.50	1.58	3.41	2.13	4.64	1.27

In considering Table XXI, the following substitutions were made:

For mean range of non-stutterers let
I = NRI
II = NRII
III = NRIII

For mean time of non-stutterers let
I = NTI
II = NTII
III = NTIII

For mean range of stutterers let
I = SRI
II = SRII
III = SRIII

For mean time of stutterers let
I = STI
II = STII
III = STIII

Now there can be presented the following twelve equations:

1. $\text{NRI} - \text{NRII} = 3.93 - 2.61 = 1.32 \pm .26$ $\quad$ $\text{O.D.} = 5.07 \times \text{P.E.}_{\text{diff.}}$
2. $\text{NRI} - \text{NRIII} = 3.93 - 2.16 = 1.77 \pm .26$ $\quad$ $\text{O.D.} = 6.8 \times \text{P.E.}_{\text{diff.}}$
3. $\text{NRII} - \text{NRIII} = 2.61 - 2.16 = .45 \pm .24$ $\quad$ $\text{O.D.} = 1.8 \times \text{P.E.}_{\text{diff.}}$
4. $\text{SRIII} - \text{SRI} = 4.64 - 2.50 = 2.14 \pm .30$ $\quad$ $\text{O.D.} = 7.1 \times \text{P.E.}_{\text{diff.}}$
5. $\text{SRIII} - \text{SRII} = 4.64 - 3.41 = 1.25 \pm .26$ $\quad$ $\text{O.D.} = 4.8 \times \text{P.E.}_{\text{diff.}}$
6. $\text{SRII} - \text{SRI} = 3.41 - 2.50 = .91 \pm .20$ $\quad$ $\text{O.D.} = 4.5 \times \text{P.E.}_{\text{diff.}}$
7. $\text{NRI} - \text{SRI} = 3.93 - 2.50 = 1.43 \pm .26$ $\quad$ $\text{O.D.} = 5.5 \times \text{P.E.}_{\text{diff.}}$
8. $\text{SRII} - \text{NRII} = 3.41 - 2.61 = .80 \pm .19$ $\quad$ $\text{O.D.} = 4.2 \times \text{P.E.}_{\text{diff.}}$
9. $\text{SRIII} - \text{NRIII} = 4.64 - 2.16 = 2.48 \pm .298$ $\quad$ $\text{O.D.} = 8.3 \times \text{P.E.}_{\text{diff.}}$
10. $\text{NTI} - \text{NTIII} = 1.50 - 1.22 = .28 \pm .05$ $\quad$ $\text{O.D.} = 5.6 \times \text{P.E.}_{\text{diff.}}$
11. $\text{STI} - \text{STIII} = 1.58 - 1.27 = .31 \pm .04$ $\quad$ $\text{O.D.} = 7.9 \times \text{P.E.}_{\text{diff.}}$
12. $\text{NTII} - \text{STII} = 2.38 - 2.13 = .25 \pm .08$ $\quad$ $\text{O.D.} = 3.1 \times \text{P.E.}_{\text{diff.}}$

TABLE XXII. *S.D.'s for range and time*

	I		II		III	
Group	Range	Time	Range	Time	Range	Time
Non-stutterers	1.29	.298	1.10	.420	1.07	.209
Stutterers	1.17	.246	.67	.382	1.59	.227

For studying Table XXII, the following substitutions were made:

For S.D. of distribution for range of non-stutterers
Let I = NDRI
II = NDRII
III = NDRIII

For S.D. of distribution for range of stutterers
Let I = SDRI
II = SDRII
III = SDRIII

For S.D. of distribution for time of non-stutterers
Let I = NDTI
II = NDTII
III = NDTIII

For S.D. of distribution for time of stutterers
Let I = SDTI
II = SDTII
III = SDTIII

Now there can follow nine equations:

1. $\text{NDRI} - \text{NDRII} = 1.29 - 1.10 = .19 \pm .185$ $\quad$ $\text{O.D.} = 1.02 \times \text{P.E.}_{\text{diff.}}$
2. $\text{NDRI} - \text{NDRIII} = 1.29 - 1.07 = .22 \pm .183$ $\quad$ $\text{O.D.} = 1.20 \times \text{P.E.}_{\text{diff.}}$
3. $\text{NDRII} - \text{NDRIII} = 1.10 - 1.07 = .03 \pm .168$ $\quad$ O.D.——————
4. $\text{SDRIII} - \text{SDRI} = 1.59 - 1.17 = .42 \pm .217$ $\quad$ $\text{O.D.} = 1.98 \times \text{P.E.}_{\text{diff.}}$
5. $\text{SDRIII} - \text{SDRII} = 1.59 - .67 = .92 \pm .189$ $\quad$ $\text{O.D.} = 4.86 \times \text{P.E.}_{\text{diff.}}$
6. $\text{SDRI} - \text{SDRII} = 1.17 - .67 = .50 \pm .145$ $\quad$ $\text{O.D.} = 3.45 \times \text{P.E.}_{\text{diff.}}$
7. $\text{NDRI} - \text{SDRI} = 1.29 - 1.17 = .12 \pm .191$ $\quad$ O.D.——————
8. $\text{NDRII} - \text{SDRII} = 1.10 - .67 = .43 \pm .141$ $\quad$ $\text{O.D.} = 3.05 \times \text{P.E.}_{\text{diff.}}$
9. $\text{SDRIII} - \text{NDRIII} = 1.59 - 1.07 = .52 \pm .209$ $\quad$ $\text{O.D.} = 2.39 \times \text{P.E.}_{\text{diff.}}$

TABLE XXIII. *Pitches of whole sentences for non-stutterers*

Observers	I	II	III
A	127	135	115
B	109	123	122
C	98	98	99
D	119	132	124
E	97	96	101
F	115	109	115
G	126	142	131
H	124	110	122
K	98	106	101
L	108	99	101
M	123	132	108
N	105	113	103
O	93	121	112
P	122	132	106
Q	96	108	101
R	107	111	116
S	106	127	113
T	115	120	113
Mean	110	117	111
S.D.	11.01	13.49	9.187

TABLE XXIV. *Pitches of whole sentences for stutterers*

Observers	I	II	III
A	130	122	138
B	132	137	131
C	127	125	125
D	109	112	113
E	98	106	100
F	106	107	105
G	170	162	104
H	125	123	100
I	165	113	113
J	115	127	102
K	113	122	115
L	134	127	118
M	142	132	150
N	104	128	122
O	124	118	111
P	135	150	148
Q	95	98	102
R	99	103	99
Mean	123	123	116
S.D.	20.74	15.64	15.83

TABLE XXV. *Means and S.D.'s for pitches of whole sentences*

Group	Mean	S.D.	Mean	S.D.	Mean	S.D.
Non-stutterers	110	11.01	117	13.49	111	9.187
Stutterers	123	20.74	123	15.64	116	15.83

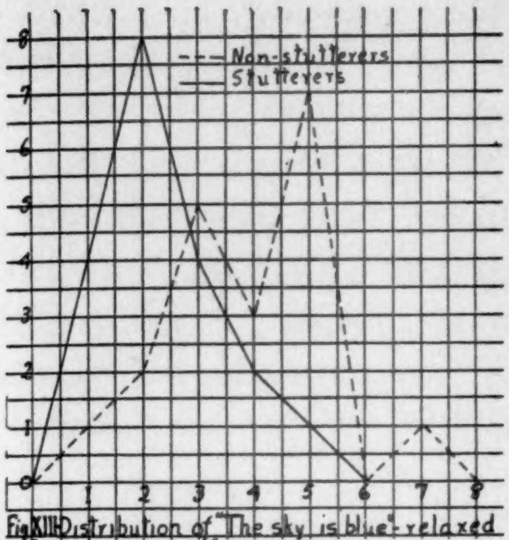


Fig XIII Distribution of "The sky is blue"-relaxed

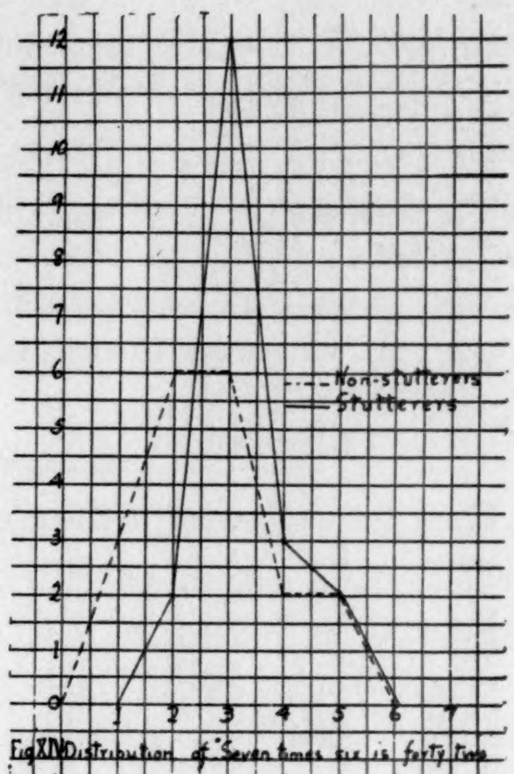


Fig XIV Distribution of "Seven times six is forty two

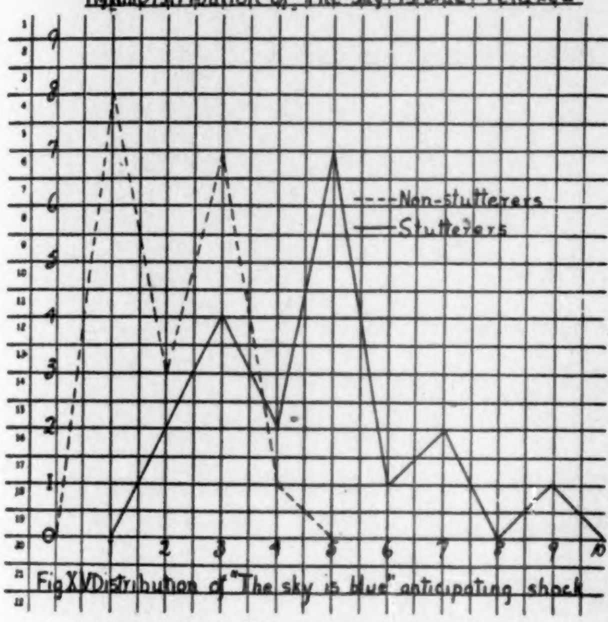


Fig XV Distribution of "The sky is blue" anticipating shock

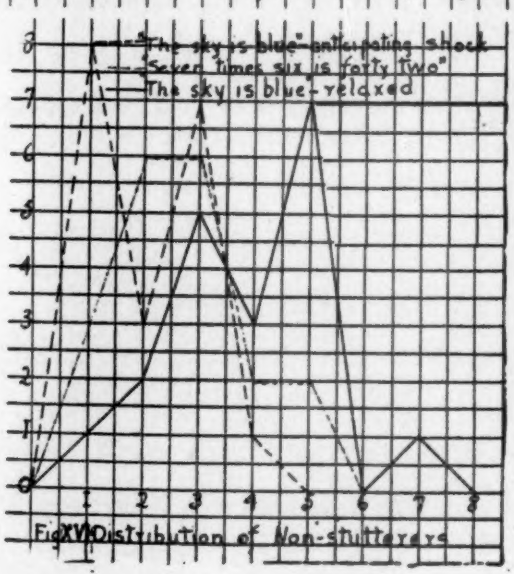


Fig XVI Distribution of Non-stutterers

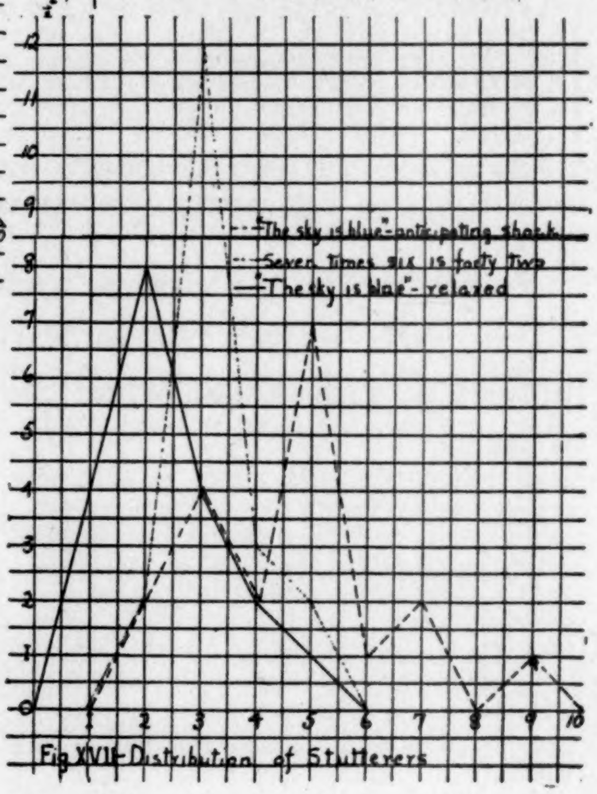


Fig XVII Distribution of Stutterers

In order to study Table XXV, the following substitutions were made:

For mean pitches of whole sentences for non-stutterers
Let I = NPI
II = NPII
III = NPIII

For mean pitches of whole sentences for stutterers
Let I = SPI
II = SPII
III = SPIII

For S.D. for pitches of whole sentences for non-stutterers
Let I = NDPI
II = NDPII
III = NDPIII

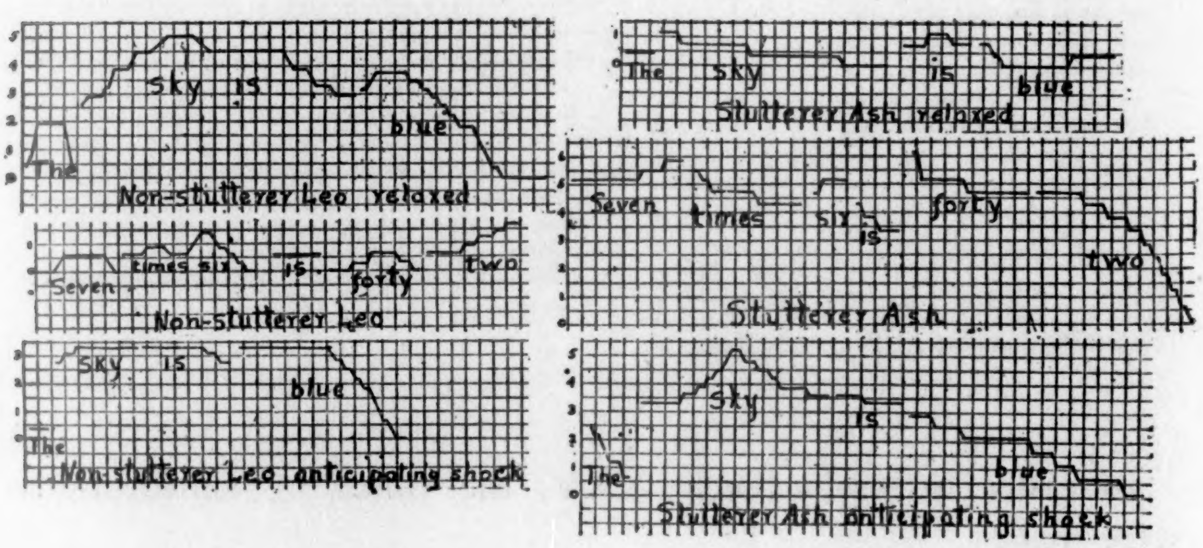
For S.D. for pitches of whole sentences for stutterers
Let I = SDPI
II = SDPII
III = SDPIII

Then the following fifteen equations are possible:

1.	NPII	— NPI	= 117	— 110	= 7	± 2.76	O.D. = 2.54 × P.E.diff.
2.	NPII	— NPIII	= 117	— 111	= 6	± 2.59	O.D. = 2.32 × P.E.diff.
3.	SPI	— SPIII	= 123	— 116	= 7	± 4.14	O.D. = 1.69 × P.E.diff.
4.	SPII	— SPIII	= 123	— 116	= 7	± 3.52	O.D. = 2.00 × P.E.diff.
5.	SPI	— NPI	= 123	— 110	= 13	± 3.73	O.D. = 3.48 × P.E.diff.
6.	SPII	— NPII	= 123	— 117	= 6	± 3.27	O.D. = 1.83 × P.E.diff.
7.	SPIII	— NPIII	= 116	— 111	= 5	± 2.9	O.D. = 1.72 × P.E.diff.
8.	SDPI	— NDPI	= 20.74	— 11.01	= 9.73	± 3.5	O.D. = 2.78 × P.E.diff.
9.	SDPII	— NDPII	= 15.64	— 13.49	= 2.15	± 2.3	
10.	SDPIII	— NDPIII	= 15.83	— 9.187	= 6.643	± 2.05	O.D. = 3.24 × P.E.diff.
11.	SDPI	— SDPII	= 20.74	— 15.64	= 5.10	± 3.72	O.D. = 1.37 × P.E.diff.
12.	SDPI	— SDPIII	= 20.74	— 15.83	= 4.91	± 3.75	O.D. = 1.31 × P.E.diff.
13.	NDPII	— NDPI	= 13.49	— 11.01	= 2.48	± 1.90	O.D. = 1.31 × P.E.diff.
14.	NDPII	— NDPIII	= 13.49	— 9.187	= 4.303	± 1.80	O.D. = 2.39 × P.E.diff.
15.	NDPI	— NDPIII	= 11.01	— 9.187	= 1.823	± 1.58	O.D. = 1.15 × P.E.diff.

* Some possible subtractions are not made as even superficial observation indicate that no legitimate differences exist.

Five distribution charts, each chart having two distribution curves, were made. As in Part II the ordinate scales give the number of individuals while the abscissa scales give the number of tones.



Readings of the three sentences for an individual of each group have been graphed. Each square in a vertical direction is one-half tone while each square in a horizontal direction is .03 second. No attention should be given to the time element in these graphs as the individuals from the time standpoint are atypical. On the other hand the graphs do show very well the differences in range of speaking the various sentences and the differences in range between the stutterer and non-stutterer in speaking the same sentence.

Statement of Findings for Part III[1]

1. The non-stutterer has a greater range in pitch when speaking under the influence of relaxation than under mental effort.
2. The non-stutterer has a greater range for speaking under relaxation than for speaking under conditions of threatened injury.
3. There is no difference in the range of the non-stutterer when he speaks under mental effort and when he speaks in the presence of threatened injury.
4. The stutterer has a greater range in pitch when speaking under mental effort than under conditions of relaxation.
5. The stutterer has a greater range when speaking in the presence of threatened injury than under conditions of relaxation.
6. The stutterer has a greater range when speaking in the presence of a threatened injury than under mental effort.
7. A non-stutterer has a greater range than the stutterer when speaking under conditions of relaxation.
8. A stutterer has greater range than a non-stutterer when speaking under mental effort.
9. The stutterer has a greater range than the non-stutterer when speaking in the presence of threatened injury.
10. Both the stutterer and the non-stutterer consume more

[1] It seemed wise again to substitute a word or two for each of the three conditions. Thus, for saying "The sky is blue" under conditions of relaxation there will be used the term relaxation, for "Seven times six is forty-two" mental effort, and for "The sky is blue" when a shock is expected, threatened injury.

time in speaking under conditions of relaxation than in the presence of a threatened injury.

11. The non-stutterer consumes more time than the stutterer in speaking under mental effort.

12. There is no difference between the stutterer and non-stutterer in the time consumed while speaking under relaxed conditions or in speaking in the presence of a threatened injury.

13. The group of stutterers had a greater dispersion of ranges in pitch when speaking under conditions of relaxation and in the presence of a threatened injury than in speaking under mental effort.

14. The group of non-stutterers had a greater variability of ranges than the stutterers when speaking under mental effort.

15. No other differences in dispersion of ranges in pitch between the two groups for the various situations or for the same group in the various conditions seemed to exist.

16. As a group the stutterers took a higher pitch for speaking under conditions of relaxation than the non-stutterers.

17. The stuttering group had a greater dispersion of pitches taken for speaking in the presence of a threatened injury than the non-stutterers.

18. No other real differences between stutterers and non-stutterers were found in regard to the average pitch at which a sentence was spoken or in regard to dispersion of pitches while speaking whole sentences.

General Conclusions

Stutterers and non-stutterers seem to differ in regard to the effect of emotional situations upon voice and auditory-repetitional speech. In regard to voice, stutterers have less variability in the pitch of a sustained tone after an emotional upheaval than under normal circumstances while non-stutterers have more variability in the pitch of a sustained tone after an emotional upset than under ordinary conditions. Thus in the case of the stutterer, emotion decreases the flexibility of the voice while in the case of the non-stutterer it increases the flexibility of the voice.

Concerning the repetition of spoken sentences, stutterers have more range in pitch under emotional conditions than under normal circumstances, while just the opposite is true of non-stutterers. For this type of speech emotional upheaval appears to increase the melody of stutterers, while it decreases the melody of non-stutterers. Under ordinary conditions the non-stutterer has the more melodious speech.

These facts open up at least two considerations which are closely related to each other. First, what are the inherent or acquired differences in the two types of observers responsible for the different effects, and second, why do the conditions of emotion bring out these inherent or acquired differences?

It is believed that the answer to these questions will throw a flood of light upon the obscure nature of stuttering.

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STUDIES IN MOTOR RHYTHM

By Robert Holmes Seashore

Scope of research; apparatus; procedure; reading of the graphic record; supplementary tests for the analysis of motor rhythm; Seashore Measures of Musical Talent; memory span for consonants and digits; pursuit or eye-hand coördination; steadiness tracing; thrust precision; motility; reaction-time; partial correlations—three variables; multiple correlations; interpretation of results; motor background and response in rhythm; analysis of sense of rhythm; other cognitive and motor factors; sensory limitations of motor rhythm; subjective aspects of motor rhythm; other possible tests of time and rhythm; motor rhythm test, automatic counter method; rhythm learning test; practice effects; free vs. regulated rhythmic action; validity of motor rhythm test; reliability of motor rhythm test; constant error; standardization of motor rhythm test; summary; bibliography.

Scope of research. The aim of this research has been to develop a measure of precision in rhythmic action and to analyze this function in relation to other motor and cognitive factors. The ultimate purpose is to provide a standard measure of rhythmic auditory-motor coördination which may be useful as one of a battery of specific tests for the prediction of individual success and ability to profit by training in timed rhythmic action such as musical performance.

Motor rhythm, as distinguished from other forms of orderly action, may be defined as a progression in action by balanced deviations in time, intensity, or quality from the simple periodicity of any regularly recurrent action. In the development and standardization of an objective measure of motor rhythm, the criterion of temporal precision has been emphasized, keeping the factors of intensity and quality objectively constant. It is understood, however, that they do enter into the test both in subjective and objective periodicity or rhythmic action.

Parallel to the development of this test of motor rhythm an analysis has evolved by means of statistical comparisons with abilities measured in a battery of other better known psychophysical tests. In this analysis three series of experiments were

conducted: the first, for the analysis of basic motor and cognitive capacities involved in rhythmic perception and action; the second, for the subsidiary factors of rhythm tests, such as sensory limitation of motor precision through the fusion threshold for sounds, the subjective aspects of motor rhythm, the relation of perception to learning in rhythmic presentation, and differences between

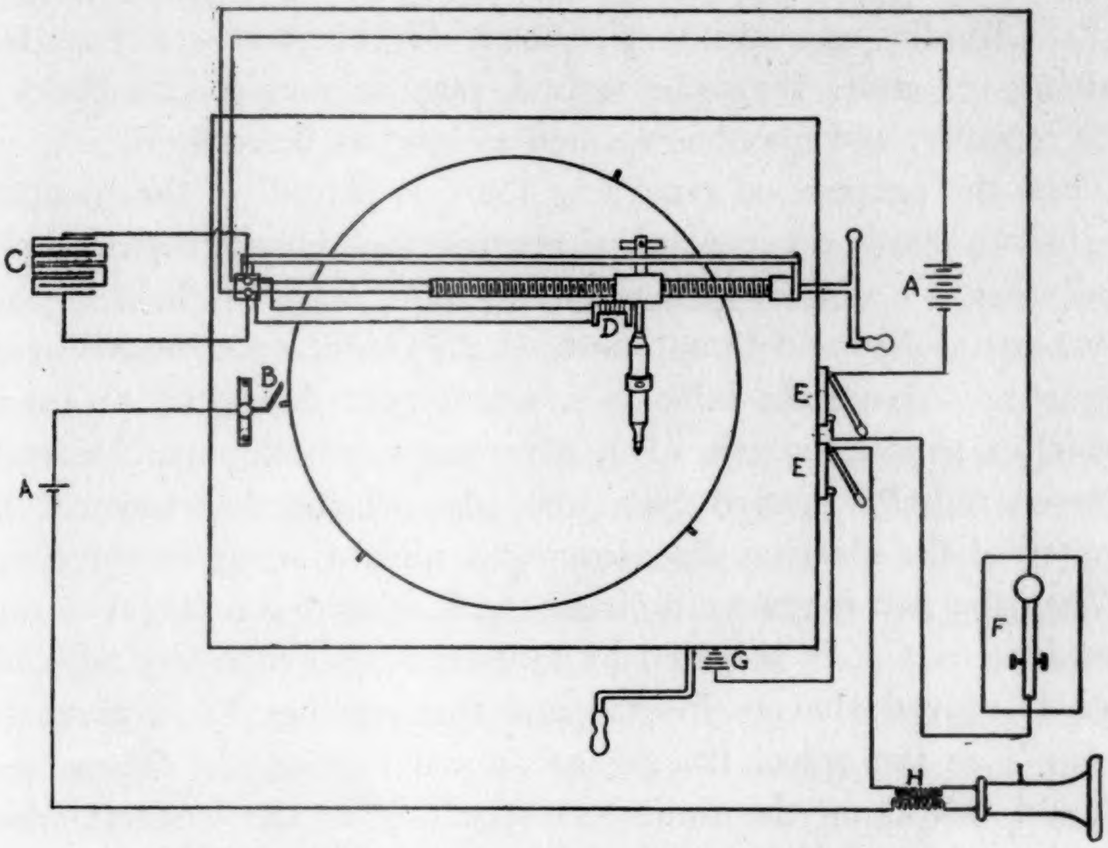

FIG. 1. Graphic apparatus for motor rhythm test

free and regulated rhythmic action; and the third, for the establishment of validity and reliability and for standardization of the motor rhythm test, and the development of norms.

Apparatus.[1] The apparatus consists of the Seashore phonograph chronograph in adapted form as shown in Fig. 1. For

[1] There has been a progressive development of methods in measuring various phases of rhythm in the Iowa laboratory for the last twenty years. About twenty years ago a device very much like the one here reported was used for the same purpose. Instead of the present type of recording apparatus a ticker tape with time lines was used, both for free and regulated rhythm. Various simpler methods intended for more elementary use proved inadequate. A high order of precision both in the sounding of the pattern and in the record has seemed to be essential for any valid test. Therefore, the one here adopted would seem to be the simplest adequate method yet devised.

the production of the sound stimulus an open phonograph (Victrola VI), from which the tone-arm and inner horn have been removed, acts as a double spring motor and turntable. Spaced about the edge of the turntable are a number of silver contact points which pass a spring brush (B) making and breaking a circuit which is completed through a dry cell (A), a small induction coil (H), a ground connection (G), and a telephone receiver (I). By the appropriate placement of the points, any pattern lasting not more than one second, may be sounded as clicks in the receiver, and may be repeated as long as desired.

For the purpose of recording there is placed on the turntable a smooth plate (reverse side of a single face phonograph record), and over it a disc of glossy white paper [2] which is held in place by a metal disc and thumbscrew at the center (not shown in the figure). Above the table is a worm gear device by means of which a simple magnet (D), carrying a fountain pen [3] may be moved radially inward from the edge of the disc towards the center of the rotating disc, leaving a spiral tracing on the paper. When the pen magnet, in circuit with four dry cells (A) and a condenser (C), is actuated by tapping a telegraph key (F), the pen is moved sharply inward and then springs back, leaving a "jog" in the spiral tracing as shown in Fig. 2. These jogs should fall along the radii corresponding to the contacts which produce the sound stimuli, and deviations from these radii may be measured. This is done by stamping radial lines marking off hundredth second intervals with a special rubber stamp, with the result shown in Fig. 2. By this method of grouping into hundredth second intervals a great saving in reading of records is made possible.

The latent time of the telephone receiver [4] is negligible. That

[2] Paper discs are cut in large quantities on a lathe, from enameled paper, 25" x 38", 80 lb. per ream.

[3] A Parker Duofold pen was especially selected for its free flow and smooth point. This insures a regular tracing with very slight friction. Blue ink is favorable.

[4] In giving of the test at a speed of 50 r.p.m. (one revolution of the phonograph turntable equaling one round of the sound pattern), in the first series of experiments a telegraph sounder was used for the sound stimulus. Instead of marking the point at which each tap should have been recorded, the machine

of the pen magnet, from time of tap to crest of jog, is about .013 second. This was constant for the same amount of current, and was easily corrected by adding that value algebraically to the constant error by which the observer anticipated or delayed his response to the sound stimulus.

Following *Seashore's* (21) method of testing the regularity of rotation of the phonograph motor,[5] the apparatus was found to be accurate within .002 second from one revolution to the next, and also reliable at least for the length of one trial, a little over one minute. This was measured at speeds of 30, 40, 50, and 60 r.p.m.

After trials of various rhythm patterns, one consisting of an eighth note, two quarter notes, and a dotted quarter note, was selected for standardization because of its simplicity and balance and the fact that it is familiar to nearly every one as a sort of "castanet" or Spanish dance rhythm. For this the contacts on the turntable were set at angles of 45, 90, 90, and 135 degrees apart, respectively. In this experiment only the intervals between successive taps were considered, but the apparatus may be used equally well for the measurement of duration.

Procedure. The observer is seated at a table with the telephone receiver and telegraph key conveniently located close together and directly in front of him,[6] and is instructed to practice tapping,

was set to work itself, and it was assumed that the latent time of the pen magnet was compensated by that of the telegraph sounder, which was similar in construction and proportions. The results indicate that there was very little error in this assumption, but the telephone receiver was later used because of the negligible latent time, the slight advantage in distinctness, and the need of only one battery to run it.

[5] A spiral tracing on smoked paper was made from the flexible stylus attached to one prong of an electrically driven 100 v.d. tuning fork. The fork was gradually moved radially in toward the center of the rotating disc by a worm gear device, and the coincidence of the nodes of corresponding waves, as seen in the illustration referred to above, shows that the phonograph may be a very regular and valuable instrument for such measurements of temporal precision.

[6] Under these conditions the sound from the key is localized in almost the same place as that from the receiver, since they are side by side and approximately in the median plane. The distance traveled by the sounds is the same. They are qualitatively different enough to avoid confusion. The observer is thus afforded the most favorable conditions for comparing the two sounds during the test.

with the key held between the tips of the thumb and first two fingers of the right (or left if left-handed) hand, keeping the forearm in an easy position. If unable to hold the key in the prescribed manner, the observer may be allowed to tap freely with a minimum movement, but this is less regular. After hearing the sound pattern a few times he is instructed to follow the rhythm as closely as possible, tapping exactly in time with it. Precision in synchronism of tap with pattern click is the chief objective.

Three trials of approximately forty-five rounds each are then made, always starting with the pen on the paper and allowing the observer to get into the swing of the action for six or eight rounds before closing the circuit connecting the key with the magnet. If the record shows a systematic error of anticipation or delay, the observer is told of this and is given opportunity to correct it.

Reading of the graphic record. The standard deviation is used as the measure of regularity (or variability) for three reasons. It is the most accurate and most representative measure of variability. It may be calculated from any assumed mean within the distribution, and incidentally gives the correction (the constant error of anticipation or delay of the observer) for finding the true mean in the same process, whereas the average deviation, which requires the same preliminary tabulation, must be calculated from the true mean which has to be found beforehand in a separate process. The constant error by which an observer stays ahead or behind the simulus pattern shows practically no relationship to his regularity. The constant error may usually be reduced by special injunction and training to approximately the limits of sensory discrimination of fusion threshold for sounds under these conditions, but the regularity is subject only to slight improvement. Hence the regularity should be measured independently of the constant error, which is most easily done by the use of the standard deviation.

In order to facilitate the calculation of the standard deviation, and to institute a uniform method of measurement, the following steps will be found convenient in the evaluation of individual

graphic records. Having stamped the graphic record (Fig. 2) with hundredth second lines, take as an assumed mean the interval immediately ahead (to the left) of the previously marked four points at which a sound of the pattern occurs. Add up the number of "jogs" in each hundredth second interval, recording in

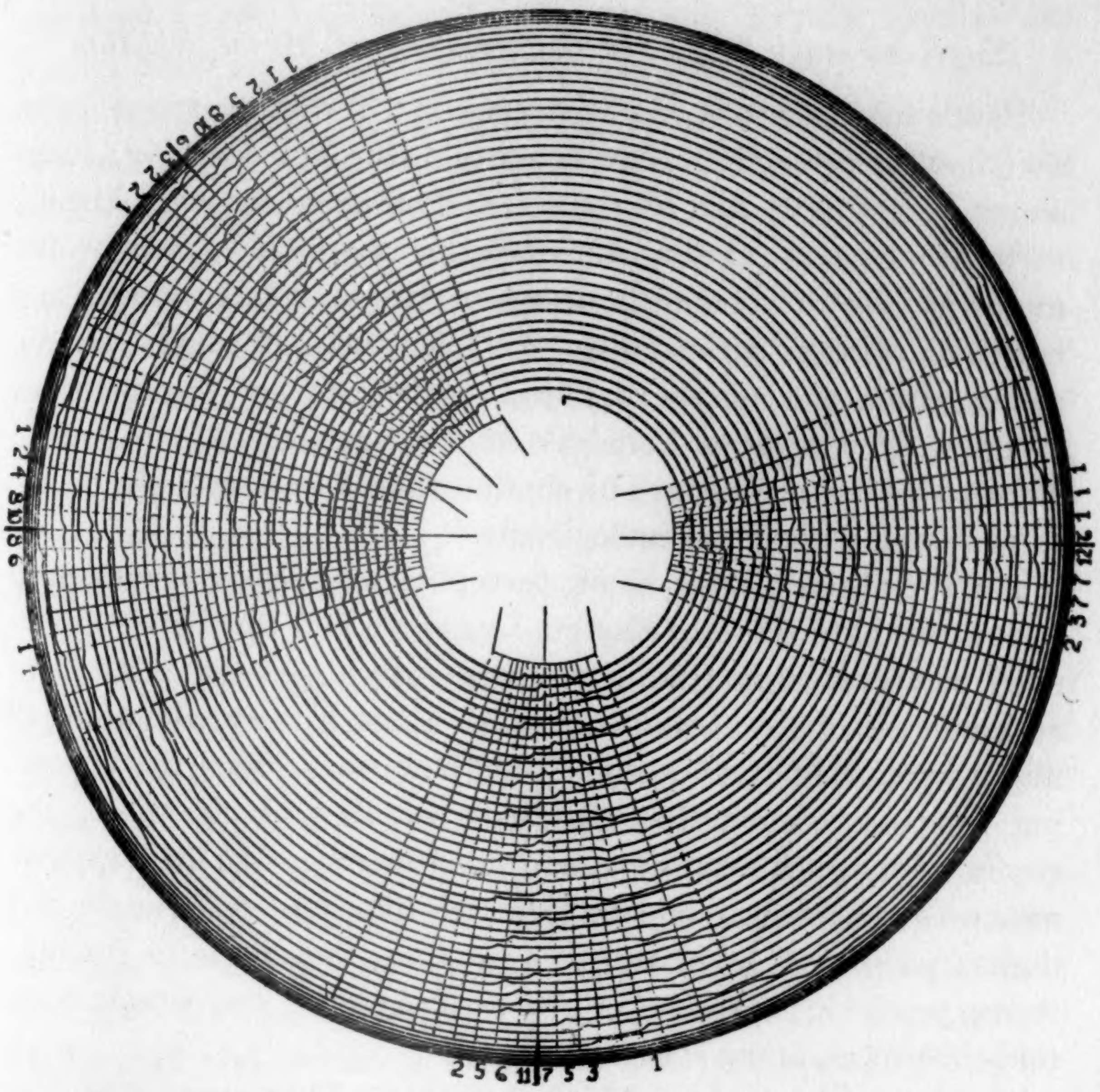

FIG. 2. Graphic record in motor rhythm test

pencil at the edge of the sheet. Do this for each of the four columns 1, 2, 3, 4, respectively, on a data sheet and combine the four distributions into one, keeping the same assumed mean. From this distribution the standard deviation may be calculated, and in the same formula is given the correction, or difference, between the actual mean of the observers tapping and the

assumed mean. This equals the constant error, to which must be added .018 second, of which .005 second is for the original assumption of a mean that much ahead of the point at which the sound stimulus occurred, and .013 is for the latent time of the pen magnet.

Supplementary Tests for the Analysis of Motor Rhythm

Psychologically, the cognitive aspects of rhythm range from the simplest perception scarcely noticed, through learning, judgments of similarity and continuity, and affective accompaniments, to the conceptual mastery of compound rhythms. Likewise the motor aspects vary from the simplest physiological processes and muscular periodic backgrounds of "filled time," through periodic accentuation, and simple rhythmic response of an incipient type, to the most complicated analytic or syncopated rhythmic action. These complicating factors of rhythm should be isolated in so far as possible and brought under control.

For the analysis of rhythmic perception and action as measured in the Seashore sense of rhythm [7] measure and this newly developed motor rhythm test, ten diverse psychophysical tests were added to these two measures to form a test battery whose scores might be treated statistically. This battery included the following tests: motor rhythm, at speeds of 40 and 50 r.p.m.; the rhythm, tonal memory, time, and pitch members of the Seashore measures of musical talent; memory span for consonants and digits; pursuit, or eye-hand coördination; steadiness in tracing; thrust precision; motility, or speed of tapping; and simple reaction-time to auditory stimulus.

Seashore Measures of Musical Talent. These tests (20) are designed to measure specific sensory capacities which enter into musical talent as a whole. They are produced on phonograph records (20) and proceed by a block of constant stimuli with norms for the translation of raw scores into percentile rank.

[7] Following the nomenclature used by *Seashore* (20, 21) capacities for sensory discrimination and the tests measuring them will be referred to as Sense of Rhythm, Sense of Time, Sense of Pitch, etc., in the interest of technological advantages.

The *Sense of Rhythm* measure consists of soft and loud taps of a telegraph sounder arranged in pairs of rhythm patterns of various difficulties. The observer records whether the pair of patterns are the same or different.

In the *Sense of Time* measure, three taps of the telegraph sounder mark off two intervals, the first of which is always of standard length, one second. The observer records whether the second interval is longer or shorter than the first.

In the *Sense of Pitch* measure, two groups of simple tones are sounded in succession and the observer judges whether the second is higher or lower.

In the *Tonal Memory* measure, series of from two to six tones are sounded twice, with one note changed in the second rendition, and the observer records the number of this changed tone.

The *Sense of Intensity* measure had already been found to have very little correlation with the Sense of Rhythm, in a study of a large number of cases by De Graff;[8] and the *Sense of Consonance* measure was not considered suitable for the present analytical purposes.

Memory span for consonants and digits. For the measurement of memory span, which was considered a possible factor in the perception of rhythm, two sets of materials, consonants and digits, were arranged by chance into groups of from four to eleven with three different trials for each order of difficulty.

The observer was instructed to listen carefully to the consonants or digits as they were pronounced in order to repeat them as soon as the experimenter has finished. The sounds were pronounced as nearly as possible in the same tone of voice, even at the end, and at the rate of about one per second. Since the scores on consonants showed very low correlation with rhythm perception and only moderate correlation with span for digits, which was of importance in other correlations, the consonant test was not included in the final correlations.

Pursuit or eye-hand coördination. This test as standardized by *Koerth* (8) is essentially a measure of eye-hand coördination

[8] Summarized by *Kwalwasser* (10).

but is also one of the best measures of general muscular coördination. The observer follows a small target moving in a circular path with a flexible stylus so connected as to register the per cent of time that the stylus is kept on the target during trials of twenty seconds each.

The disc is rotated at sixty revolutions per minute and the observer given about five revolutions in which to catch up with the moving target with the stylus. The proportion of time during which he is able to keep the stylus on the target for the next twenty revolutions is registered upon the counter. Two hundred constitutes a perfect score but none of the observers reached this point in the first twenty trials which constitute the test, although it is possible to do it with more practice. The average of the last five trials is reduced to percentile rank through the norms available and taken as representative of each person's achievement.

Steadiness tracing. This is one of the older tests described by *Whipple* (29). The skill measured is that of steadiness in drawing a stylus through a narrow wedge with the arm held free from support but steadied to some extent by holding the stylus against the tracing board, which was of standard form. The method was simplified in that the movement was always made toward the body and with the right hand, and the observer was instructed to trace the entire length of the wedge on each trial in order to get practice on the most difficult parts. The accomplishment was measured by the point along a centimeter scale at which the first contact was made, and the average of twenty-five trials counted as the score. Three practice trials were allowed in which the observer was told to make the complete stroke in about nine seconds. After the first five or ten trials almost no improvement was made.

Thrust precision. Measuring somewhat the same skill as that found by the Whipple tracing test, this test differs from that in using a short vertical thrusting and retracting movement of the hand which is entirely unsupported. It is thus also a measure of steadiness and to some extent of eye-hand muscular coördination in very slow movement. The apparatus consists of a brass plate

five inches square having nine holes of graduated sizes from 13 mm. to 2.5 mm. in diameter, so wired that contact of the stylus with the face of the plate or side of the hole will actuate a small electric buzzer.

The brass plate lies flat on the table in front of the observer's right shoulder. The observer is shown how to place the stylus very carefully in the hole until it hits bottom, using a purely vertical movement and keeping the arm free from the table. Each of the holes is tried in succession, beginning with the easiest, which counts nine points, to the most difficult which counts one point. After three preliminary trials the first two mistakes, if any, are recorded for each trial of the twenty-five which constitutes the test. A perfect score is zero. Many observers completed one or two trials without error. The best record, made by a rifleman, was fourteen perfect trials out of the possible twenty-five. The average of twenty-five trials is taken as the score.

Motility. Ability to tap at maximum speed for a short period of time is measured by the motility test standardized by *Ream* (16). A standard telegraph key with from one to three millimeters swing and approximately one hundred grams spring resistance was used to actuate an electric counter, and timed automatically by a metronome with a mercury cup device. After having tapped about one second the number of taps for the following five seconds were recorded on the counter, and the average of twenty-five such trials taken as the individual score.

Reaction-time. Simple reaction-time to auditory stimulus was measured on the *Seashore* (22) spark chronoscope. The warning signals "ready," and "set," and the stimulus, were given at intervals of about one second each, with care taken to vary the intervals slightly from one trial to the next. Upon hearing the stimulus, a click in a telephone receiver held to the ear, the observer tapped a break key which marked the point in the swing of a pendulum at which the reaction occurred. An average of twenty-five trials were taken as the measure.

TABLE I. *Test scores*

Case	M.R. 50 V.	M.R. 50 C.E.	M.R. 40 V.	M.R. 40 C.E.	R.	T.	P.	T.M.	M.C.	M.D.	Pur.	S.T.	T.P.	Mot.	R.T.
1	2.0	—0.6	2.2	— .7	47	97	36	50	7	7	93	20.0	3.3	42	20
2	3.0	—0.8	2.3	+2.6	89	4	40	45	5	6	95	20.4	1.7	34	16
3	4.5	—2.4	2.7	+1.7	35	22	2	0	7	7	93	22.2	4.0	41	12
4	3.0	+2.4	2.7	+2.4	89	95	91	97	7	6	68	20.8	2.8	51	14
5	2.6	—1.6	2.1	+2.9	94	10	9	15	8	8	74	20.4	5.4	42	15
6	4.7	—1.8	4.6		89	28	11	7	7	6	29	14.2	6.4	33	15
7	2.4	+0.4	2.3		89	11	26	23	6	7	98	21.0	1.3	42	14
8	1.8	—1.1	1.9	+2.1	99	100	63	55	7	9	100	21.6	4.1	50	14
9	2.8	+1.4	2.1	+ .3	96	78	56	95	8	9	9	20.2	1.2	35	16
10	2.4	—1.5	2.3	+1.5	96	87	81	100	6	7	9	20.1	2.8	50	13
11	2.4	+1.5	1.9	—1.3	77	85	26	65	7	8	92	23.1	2.7	49	15
12	3.2	+1.9	2.5	+1.4	36	98	76	75	7	11	100	23.6	3.1	55	13
13	2.9	—1.1	3.0	—2.8	91	95	40	27	7	6	73	34.2	2.8	34	19
14	1.7	+1.1	2.7	+1.3	96	63	81	55	8	8	100	20.2	1.6	53	17
15	3.0	—0.1	3.3	+1.8	58	79	40	45	6	6	86	20.5	3.9	38	14
16	2.1	—1.5	2.0	+2.5	58	7	23	30	6	8	93	21.5	2.8	32	13
17	2.0	+0.6	2.3	—1.04	96	94	17	95	7	9	96	19.7	2.0	48	14
18	1.9	—2.1	3.0	+1.0	91	97	87	83	7	10	95	18.0	2.1	47	14
19	3.1	+0.9	3.4	—2.1	80	42	11	60	8	8	92	21.0	1.4	40	16
20	2.0	+	2.6	+5.1	58	13	70	83	7	7	100	22.0	1.8	36	11
21	1.9	+2.4	2.8	+0.3	98	94	76	99	7	9	96	20.0	5.2	48	17
22	2.6	+1.8	3.2	+3.5	96	100	95	75	7	11	31	16.0	6.4	42	16
23	1.9	+0.8	1.8	+5.5	96	100	76	87	7	11	100	22.0	1.8	47	14
24	2.6	+1.5	2.1	+1.0	77	48	81	91	7	8	100	23.0	2.0	40	12
25	2.5	—1.1	3.3	—1.3	69	32	87	37	5	6	100	21.0	4.2	51	13
26	2.8	—0.6	2.4	+0.9	69	6	56	39	9	10	92	17.0	8.0	39	16
27	2.2	+0.7	3.1	+2.8	48	6	12	9	6	6	93	20.0	3.5	41	18
28	3.2	—1.4	3.0	+1.6	40	54	36	4	6	6	91	18.0	2.1	46	13
29	1.7	—1.6	2.0	+1.5	100	90	76	100	8	10	77	21.0	3.3	48	14
30	2.6	+2.6	3.2	+1.1	58	13	27	10	7	7	95	22.0	4.3	45	17
31	2.2	—0.5	2.2	—0.1	58	48	21	65	6	7	96	22.0	3.2	43	16
32	3.0	—2.6	3.1	+3.4	84	100	15	30	6	6	57	15.0	5.2	43	17
33	4.5	—2.6	2.7	+4.0	69	74	29	13	5	6	90	14.0	3.4	38	17
34	2.7	—0.3	3.4	+2.1	89	97	45	55	7	8	100	23.0	1.9	49	16
35	2.0	+2.0	2.3	+1.4	87	87	56	83	11	10	86	21.0	2.6	44	13
36	2.4	0.0	2.8	+6.2	58	67	15	5	7	6	62	19.0	1.3	45	16
37	4.8	—0.8	2.7	+2.9	35	20	29	41	6	6	31	16.0	4.0	38	14
38	4.0	—1.8	3.7	+5.5	1	28	12	1	6	7	100	22.0	3.0	51	17
39	2.1	+0.7	1.7	—0.2	91	97	63	91	8	8	98	20.0	5.1	52	14
40	2.2	—0.5	2.2	—0.1	94	97	45	79	7	8	90	22.0	1.1	39	12
41	3.1	+1.8	3.7	+0.4	89	13	45	45	6	8	91	15.0	3.4	36	17
42	5.0	—3.0	5.0		3	15	23	19	6	7	18	22.0	7.7	38	20
43	2.7	+0.9	3.5	+4.9	47	96	56	83	5	5	37	23.0	2.3	45	14
44	4.2	—3.8	5.0		5	5	91	0	6	8	22	19.0	4.6	50	14
Mean	2.76		2.75		72.2	58.7	47.2	51.3	6.8	7.7	78.3	20.0	3.3	43	15
S.Dev.	0.88		0.79		27.0	36.6	27.8	33.3	1.1	0.6	25.3	2.7	1.7	5.8	2
Range	1.7–5		1.7–5		1–100	1–100	1–100	1–100	5–11	5–11	1–100	14–24	1.1–8	32–55	11–20

[*Legend for Table 1*]

Symbol	*Test*	*Unit of Measurement*
M.R. 50*	Motor Rhythm, 50 r.p.m.	.01 second
M.R. 40	Motor Rhythm, 40 r.p.m.	.01 second
V.	Variability (of M. Rhythm)	standard deviation .01 second
C.E.	Constant Error (of M. Rhythm)	.01 second
R.	Sense of Rhythm	percentile rank
T.	Sense of Time	percentile rank
P.	Sense of Pitch	percentile rank
T.M.	Tonal Memory	percentile rank
M.C.	Memory Span for Consonants	letter
M.D.	Memory Span for Digits	digit
Pur.	Pursuit (eye-hand coördination)	percentile rank
S.T.	Steadiness Tracing	centimeters, on scale 1–25
T.P.	Thrust Precision	average errors, weighted 1–9
Mot.	Motility	average number taps in 5 seconds
R.T.	Reaction-time	.01 second

* In tabulation of data, percentile rank is used wherever possible, except in the case of motor rhythm, when variability and constant error are both stated in terms of raw score for the purpose of direct comparison.

TABLE II. *Zero order of correlations**

	R.T.	Mot.	T.P.	S.T.	Pur.	M.D.	T.M.	P.	T.	R.	M.R.40
M.R. 50	.14	.28	.39	.32	.46	.40	.54	.40	.42	.64	.64
M.R. 40	.31	.02	.38	.23	.41	.40	.46	.15	.33	.54	
R.	.17	.10	.22	.12	.22	.44	.56	.32	.52		
T.	.06	.35	.20	.13	.06	.28	.57	.37			
P.	.32	.39	.04	.12	.05	.50	.64				
T.M.	.33	.17	.29	.26	.03	.51					
M.D.	.16	.28	.07	.46	.20						
Pur.	.15	.40	.25	.31							
S.T.	.26	.37	.30								
T.P.	.33	.04									
Mot.	.10										
R.T.											

* Legend same as in Table I.

Reliability — M.R.40 — Tr. 1 — vs. Tr. 2, r = .80 by Brown's formula, x 2 (actual length of test), r = .89.

Since the size of the probable error for forty-four cases is the same for any given value of r, and since the per cent of reduction of the standard error of estimate over zero correlation likewise depends on the value of r, the equivalent values of P.E. and the per cent reduction of standard error of estimate for each value of r may be conveniently given in tabular form as follows:

TABLE III. *Predictive value of Pearson coefficients of correlation*

r	P.E.	% reduction of S.E. of Est.
.00	.10	0.00
.10	.10	0.05
.20	.10	2.02
.30	.09	4.60
.40	.08	8.90
.50	.07	13.40
.60	.06	20.00
.70	.05	28.60
.80	.04	40.00
.86	.02	50.00
.90	.02	56.40
.95	.01	68.90
.96	.01	72.00
.97	.01	75.70
.98	.004	80.00
.99	.002	86.00
1.00	.00	100.00

These values of P.E. are approximately the same for equivalent values of r in zero, partial, or multiple correlations. Although these values of r are not corrected for attenuation due to lack

of high reliability of some of the measures, it should be remembered that the actual values of r which are obtained, are systematically too low on this account. Likewise the per cent of reduction of standard error of estimate is calculated on the basis of thoroughly reliable tests and for this reason these values are also systematically low. Considering a coefficient of correlation as significant only when it exceeds three times its P.E., the lowest significant value of r in this series of tests is .28.

Partial correlations: three variables. Since these psychophysical tests measure capacities which overlap in various degrees, the zero order of correlations have been further treated by partial correlations which give the degree of correlation between any two tests with the influence of a third overlapping test thrown out. While the zero order of correlations are important in showing the general relationship of any two tests, partial correlations are more valuable for the isolation of separate factors. For instance, the first set of partial correlations involving motor rhythm 50 r.p.m., sense of rhythm, and steadiness tracing, is stated as follows in comparison with the zero order values.

	Zero order		Partials	
1. M.R. 50	r_{12}	.64	$r_{12.3}$	.72
2. S.R.	r_{13}	.32	$r_{13.2}$	.52
3. S.T.	r_{23}	—.12	$r_{23.1}$	.11

These three tests have been assigned arbitrary numbers, motor rhythm being 1, sensory rhythm 2, etc. The zero order correlation between motor rhythm and sense of rhythm may then be stated as r_{12}. The symbol $r_{12.3}$ is likewise read as " the correlation between motor rhythm (1) and sense of rhythm (2) after the influence of muscular coördination (S.T., 3) has been thrown out." Referring to the zero order of correlations above, motor rhythm is moderately related to sense of rhythm and less closely to steadiness tracing, while sense of rhythm and steadiness tracing are not related. Thus motor rhythm is not a simple factor and the correlation between two rhythm tests is lowered by the presence of an outside factor in motor rhythm. After partialling out this extraneous muscular factor the correlation between motor rhythm and sense of rhythm, $r_{12.3}$ equals .72. Since there is

no correlation between sense of rhythm and steadiness tracing in the first place, partialling for $r_{23.1}$ makes no significant change.

This is one use of partial correlation, namely the isolation of an extraneous factor in the relationship between two other tests. Another use is the isolation of common or assisting factors, the removal of which lowers the correlations between all three tests considered. An example is that of Partial Correlation No. 18, involving sense of rhythm, memory span, and tonal memory. Here it is quite evident that some form of memory is the common factor, and from the fact that there is a similar relation between motor rhythm, sense of rhythm, and tonal memory, and similar groups, it seems probable that it is a type of kinaesthetic memory.

TABLE IV. *Index to partial correlations*

(Legend to Table V)

1.	Motor Rhythm 50	; Sense of Rhythm; Steadiness Tracing
2.		; Sense of Rhythm; Pursuit
3.		; Sense of Time; Pursuit
4.		; Sense of Time; Steadiness Tracing
5.		; Tonal Memory; Pursuit
6.		; Tonal Memory; Pitch
7.		; Sense of Rhythm; Time
8.		; Pursuit; Steadiness Tracing
9.		; Sense of Rhythm; Tonal Memory
10.		; Memory Span; Tonal Memory
11.		; Sense of Rhythm; Memory Span
12.		; Motor Rhythm 40; Motility
13.		; Thrust Precision; Motility
14.	Sense of Rhythm	; Sense of Time; Tonal Memory
15.		; Tonal Memory; Pitch
16.		; Memory Span; Sense of Time
17.		; Memory Span; Tonal Memory
18.	Memory Span	; Tonal Memory; Sense of Pitch
19.		; Steadiness Tracing; Pursuit

TABLE V. *Partial correlations, 1 to 19*

No. 1		
1—Motor Rhythm 50	$r_{12} = .64$	$r_{12.3} = .72$
2—Sense of Rhythm	$r_{13} = .32$	$r_{13.2} = .52$
3—Steadiness Tracing	$r_{23} = .12$	$r_{23.1} = .11$
No. 2		
1—Motor Rhythm 50	$r_{12} = .64$	$r_{12.3} = .62$
2—Sense of Rhythm	$r_{13} = .46$	$r_{13.2} = .48$
3—Pursuit	$r_{23} = .22$	$r_{23.1} = -.12$
No. 3		
1—Motor Rhythm 50	$r_{12} = .42$	$r_{12.3} = .44$
2—Sense of Time	$r_{13} = .46$	$r_{13.2} = .48$
3—Pursuit	$r_{23} = .06$	$r_{23.1} = -.164$

TABLE V—Continued

No. 4		
1—Motor Rhythm	$r_{12} = .42$	$r_{12.3} = .40$
2—Sense of Time	$r_{13} = .32$	$r_{13.2} = .29$
3—Steadiness Tracing	$r_{23} = .13$	$r_{23.1} = .00$
No. 5		
1—Motor Rhythm	$r_{12} = .54$	$r_{12.3} = .59$
2—Tonal Memory	$r_{13} = .46$	$r_{13.2} = .53$
3—Pursuit	$r_{23} = .03$	$r_{23.1} = -.30$
No. 6		
1—Motor Rhythm 50	$r_{12} = .54$	$r_{12.3} = .40$
2—Tonal Memory	$r_{13} = .40$	$r_{13.2} = .10$
3—Sense of Pitch	$r_{23} = .64$	$r_{23.1} = .55$
No. 7		
1—Motor Rhythm 50	$r_{12} = .64$	$r_{12.3} = .54$
2—Sense of Rhythm	$r_{13} = .42$	$r_{13.2} = .25$
3—Sense of Time	$r_{23} = .52$	$r_{23.1} = .36$
No. 8		
1—Motor Rhythm 50	$r_{12} = .46$	$r_{12.3} = .40$
2—Pursuit	$r_{13} = .32$	$r_{13.2} = .21$
3—Steadiness Tracing	$r_{23} = .31$	$r_{23.1} = .19$
No. 9		
1—Motor Rhythm	$r_{12} = .64$	$r_{12.3} = .49$
2—Sense of Rhythm	$r_{13} = .54$	$r_{13.2} = .29$
3—Tonal Memory	$r_{23} = .56$	$r_{23.1} = .38$
No. 10		
1—Motor Rhythm	$r_{12} = .40$	$r_{12.3} = .18$
2—Memory Span	$r_{13} = .54$	$r_{13.2} = .43$
3—Tonal Memory	$r_{23} = .51$	$r_{23.1} = .38$
No. 11		
1—Motor Rhythm 50	$r_{12} = .64$	$r_{12.3} = .56$
2—Sense of Rhythm	$r_{13} = .40$	$r_{13.2} = .17$
3—Memory Span	$r_{23} = .44$	$r_{23.1} = .25$
No. 12		
1—Motor Rhythm 50	$r_{12} = .64$	$r_{12.3} = .67$
2—Motor Rhythm 40	$r_{13} = .28$	$r_{13.2} = .35$
3—Motility	$r_{23} = .02$	$r_{23.1} = -.22$
No. 13		
1—Motor Rhythm 50	$r_{12} = .39$	$r_{12.3} = .39$
2—Thrust Precision	$r_{13} = .28$	$r_{13.2} = .29$
3—Motility	$r_{23} = .04$	$r_{23.1} = -.08$
No. 14		
1—Sense of Rhythm	$r_{12} = .52$	$r_{12.3} = .30$
2—Sense of Time	$r_{13} = .57$	$r_{13.2} = .39$
3—Tonal Memory	$r_{23} = .56$	$r_{23.1} = .38$
No. 15		
1—Sense of Rhythm	$r_{12} = .56$	$r_{12.3} = .50$
2—Tonal Memory	$r_{13} = .32$	$r_{13.2} = .04$
3—Sense of Pitch	$r_{23} = .63$	$r_{23.1} = .58$

TABLE V—Continued

No. 16		
1—Sense of Rhythm	$r_{12} = .44$	$r_{12.3} = .35$
2—Memory Span	$r_{13} = .52$	$r_{13.2} = .46$
3—Sense of Time	$r_{23} = .28$	$r_{23.1} = .07$
No. 17		
1—Sense of Rhythm	$r_{12} = .44$	$r_{12.3} = .21$
2—Memory Span	$r_{13} = .56$	$r_{13.2} = .41$
3—Tonal Memory	$r_{23} = .51$	$r_{23.1} = .36$
No. 18		
1—Memory Span	$r_{12} = .51$	$r_{12.3} = .28$
2—Tonal Memory	$r_{13} = .50$	$r_{13.2} = .26$
3—Sense of Pitch	$r_{23} = .64$	$r_{23.1} = .51$
No. 19		
1—Memory Span	$r_{12} = .46$	$r_{12.3} = .43$
2—Steadiness Tracing	$r_{13} = .20$	$r_{13.2} = .07$
3—Pursuit	$r_{23} = .31$	$r_{23.1} = .25$

Multiple correlations. To get the best estimate of a score in one test, knowing scores in two other related tests, the formula $r_{1.23} = \sqrt{1 - k^2_{1.23}}$ is used, in which $k_{1.23} = \sqrt{1 - r^2_{12}} \times \sqrt{1 - r^2_{13.2}}$, the values r_{12} and $r_{13.2}$ being already known from zero and partial correlations which must previously have been calculated. Solving the multiple correlation formula for the best estimates of scores in motor rhythm from knowledge of two other related tests we obtain the following values of r, the coefficient of correlation:

Best estimate of motor rhythm 50, knowing sense of rhythm and pursuit scores, r equals .74, P.E., .04, or a reduction in the standard error of estimate of 34 per cent over zero correlation.

Best estimate of motor rhythm 50 knowing sense of rhythm and steadiness-tracing scores, r equals .76, P.E., .04, or a reduction of 35 per cent in the standard error of estimate over zero correlation.

Best estimate of motor rhythm 50 knowing sense of time and pursuit scores, r equals .61, or a reduction of 21 per cent in the standard error of estimate over zero correlation.

In other words, in so far as a multiple correlation is valid for only forty-four cases, the best estimate of ability in motor rhythm is furnished by a knowledge of scores in perception of rhythm and a measure of general muscular coördination. From these

scores it is possible to derive an estimate of score in motor rhythm which will be less in error by 35 per cent than a pure guess.

Interpretation of results. The results of the zero order of correlations of the Series I tests with motor rhythm 50 are as follows: (From Table II)

	r	P.E.
Sense of Rhythm (perception)	.64	.06
Sense of Time	.42	.08
Sense of Pitch	.40	.08
Tonal Memory	.54	.07
Memory Span (digits)	.46	.08
Pursuit	.46	.08
Steadiness Tracing	.32	.09
Thrust Precision	.39	.08
Motility	.28	.09
Reaction Time	.14	.10

The results of partialling among the most important zero order correlations show that in their relation to motor rhythm the tests may be divided into three groups. The first group is represented by the rhythm, time, pitch, and tonal memory measures of the Seashore musical talent series, and memory span for digits; consonants are not well suited for grouping and memory span in terms of these units shows no correlation with sense of rhythm. The second group consists of muscular coördination measures—pursuit, tracing, and thrusting. A third group, of very slight importance, is that of the speed tests of reaction-time and motility.

The first group of tests, rhythm, pitch, time, and tonal memory, and memory span for digits show a "halo" effect; that is, they overlap and correlate among themselves about the same as with motor rhythm, with coefficients of from .40 to .64. The partial correlations tend to show that there is but one dominant factor which is common to all. Partial correlation numbers 7, 9, 10, 11, 14, 15, 16, 17, and 18 are of particular importance on this point. The measures of rhythm and tonal memory are concerned with longer and slightly more complex aspects of this common factor, more comparable to the pattern of the motor rhythm test, than are the measures of time and pitch, which are simple liminal measures. For this reason, throwing out of either sense of rhythm or tonal memory from the zero correlations usually lowers the partial values considerably more than for

throwing out time, pitch, or memory span. Since this general factor is common to such diverse measures as motor rhythm, sense of rhythm, tonal memory, sense of time, and sense of pitch, and memory span for digits, but not to the muscular coördination or speed tests, we are afforded several lines of evidence as to its nature. If it were degree of attention we might expect it to be shown up rather strongly in the reaction-time test, in which the observer's attention is closely concentrated on a simple task for a short time. The fact that reaction-time correlates only slightly, but always positively, with the other measures suggests that attention is but a very minor factor. If it were purely a matter of memory span, the correlations of memory span for digits should be considerably higher than they are. Referring again to the fact that this common factor is measured most completely by the sense of rhythm, tonal memory, and the motor rhythm tests and in a lesser degree by the sense of pitch and sense of time measures and memory span for digits, a factor still more basic and applicable to these conditions than either attention or memory span is indicated. This factor which is best measured by motor rhythm, sense of rhythm, and tonal memory is postulated as *kinesthetic memory* or the ability to apprehend and retain a fine muscular set for a sufficient length of time to repeat or compare the action with a second presentation.

In their closer correlations with motor rhythm, the measures of sense of rhythm and tonal memory may be so connected not only by the fact that they measure longer patterns which are more comparable to that of the motor rhythm test pattern, than are the simpler groups of the sense of pitch and sense of time measures, but also through a somewhat specialized rhythmic kinesthetic memory. On this point of the more efficient measurement of general kinesthetic memory versus the additional factor of a specialized rhythmic type, we have experimental and statistical evidence from two tests; those involving memory span for consonants, and for digits. Proficiency in memory span for consonants was of no predictive value in relation to success in sense of rhythm, while the same form of test using numbers instead

of consonants was of some value, having coefficients of correlation of .44, P.E. .08, and .40, P.E. .08, with sense of rhythm and motor rhythm, respectively. This seems to be due chiefly to the fact that consonants have little, if any, associative value, being in fact almost the same as nonsense syllables, while long numbers are nearly always handled by grouping into threes in accordance with our arithmetic system, and this subjective grouping involves something of the temporal, qualitative and intensive balanced deviations which are found in the perception of rhythm patterns. Memory span for digits also correlates .28, P.E. .09, with the sense of time, and .50, P.E. .07, and .51, P.E. .07, with sense of pitch and tonal memory, respectively.

Now if a measure of extent of general memory span is not highly correlated with success in either sense of rhythm or motor rhythm, then it would seem that there must be a specialized type of rhythmic kinesthetic memory which is best measured by motor rhythm and sense of rhythm and approximated by tonal memory, where it is probable that subjective intensive and temporal grouping may be projected upon the regular tonal series. Such a specialized rhythmic kinesthetic memory might be called *"basic rhythm"* since it is a distinguishing factor between rhythm tests and other related sensory measures.

The advantages of memory and rhythm are reciprocal, for one might appreciate a rhythm just at the moment of hearing it and be unable to remember it, and thus derive greater pleasure if he could reproduce the experience in order to grasp more of its continuity and development; and, conversely, rhythmical presentation of material aids in memorizing. An instance of a very elementary and subjective form of rhythmic perception is that in which facility in grouping appears to be a greater extent in memory span for digits than in the same measure involving consonants.[9]

[9] *H. F. Adams* (1) reports the result of some class experiments in immediate memory for groups of nine digits, read at a rate of ninety to a hundred per minute, in five rhythms and also without accent. Iambic rhythm gave slightly better, and trochaic slightly poorer results than the non-rhythmic, while the dactylic, anapaestic and amphibracic rhythms gave better results than the iambic.

Kinesthetic memory, or the ability to apprehend and retain a muscular set for a sufficient length of time to repeat or compare the action with a second presentation, may now be considered in its relation to auditory-kinesthetic imagery. The same type of imagery is important in both cognitive and motor aspects of rhythm, and the neurological explanation of the reconstitution of the stimulus through proprioceptive or " short circuit " stimulation should hold equally well for both the incipient, resonant rhythmic response of the imagery and the explicit response of motor rhythm.

To summarize the relationship of the first group of cognitive tests to motor rhythm: the factor of general kinesthetic memory is common to all of these tests, but is more adequately measured by the sense of rhythm and tonal memory measures than by the sense of time, sense of pitch, and memory span for digits; in addition to the general factor of kinesthetic memory there is a specialized rhythmic kinesthetic memory designated as " basic rhythm " which is common to the sense of rhythm and motor rhythm, and approximated subjectively through the measure of tonal memory. Span of memory, sense of time, and sense of pitch are of slight significance to precision in motor rhythm except through the common factor of general kinesthetic memory.

A second group of tests, those measuring general motor coördination or precision in overt actions, are of somewhat less value than the first group for the prediction of ability in motor rhythm, and represent a different kind of capacity from that measured by the Seashore measures of musical talent, and memory span for digits. However, a knowledge of scores on these two types of tests representing kinesthetic memory in its general and specialized rhythmic forms, and muscular coördination, forms the best basis for prediction of ability in motor rhythmic precision, as shown by the multiple correlations.

The third group of tests, those measuring speed, show very little correlation with motor rhythm at 50 r.p.m. and almost none at 40 r.p.m. This may be explained by the fact that neither test

demands very great speed to make a good record, but if given at 60 r.p.m., or higher, it might be important.

Another correlation between scores on sense of rhythm and sense of time, on all the men (290) in the elementary psychology class of the University of Iowa, showed a correlation of —.02, P.E. .04. However, *DeGraff,*[10] working on a still larger group including children, found a correlation of .25 between these two tests, and from the improvement shown in individual retesting, it seems probable that there is some moderate degree of correlation between rhythm and time through the factor of general kinesthetic memory, but less than would be expected from the general points of view expressed by many writers on the nature of rhythm.

Motor background and response in rhythm. Motor activity[11] first becomes of importance in rhythm and other forms of presentation through the muscular basis of attention. As pointed out by *Seashore,*(**21**) attention, involving general muscular tonus, is at first heightened both voluntarily and involuntarily for the initiation of rhythm. As the rhythm proceeds and is repeated, there is a tendency toward automatism and the efficient secondary-passive form of attention, which rises occasionally to mixed voluntary and passive attention as varying trends are developed in the rhythmic passages. *Ruckmick* (**18**) finds an increase of auditory and other imagery with decrease of kinesthetic importance after the rhythm is once initiated. *Dunlap* (**3**) holds that rhythm may be perceived while in a perfectly relaxed state. The writer would, however, interpret the relaxation as only a matter of degree, and would agree that attention need not be the primary or governing factor in rhythm.

Aside from the general muscular tonus which is involved in all forms of attention, there is a special type of background of muscular periodicity which is a possible factor of temporal and intensive ordering in the perception of rhythm. There need not be

[10] Summarized by *Kwalwasser* (**10**).

[11] The writer has omitted a historical or analytical summary of the investigations in rhythm because of the fact that this has been done by a number of writers, such as *Miner* (**14**), *Weld* (**28**), *Isaacs* (**4**), *Jacobs* (**5**), and others. Likewise an extensive bibliography is unnecessary because this is well done in *Ruckmick's* (**18**) bibliography and supplements.

actual pendular movements of the limbs, or overt contraction and relaxation of other muscles. Small implicit movements may be regulated perhaps by imagery, which reconstitutes the stimulus in miniature and gives a background of regularity and continuity. Neurologically, this imagery, or reconstitution of the stimulus, might take place through proprioceptive or " short circuit " stimulation of the various muscles involved, such as throat, head, and limbs. The resulting slight movements may be only a subliminal " filled time " background for temporal and intensive judgments. or they may themselves afford a distinct impression[12] of rhythmic unity and balance.

The motor periodic background may be either of the involuntary musculature, such as the heart beat, or other organic processes, or more probably of the semi-voluntary and voluntary musculature such as the breathing and vocal apparatus which afford the necessary flexibility to adapt themselves to various rates and patterns of rhythm. With practice, this slight muscular action may be condensed and controlled until it is almost unnoticed. It is certain that civilization constantly suppresses overt muscular action of many types so that they come to be expressed only in incipience. *Patterson* (15) and *Wallaschek* (27) suggest that we have lost untold pleasures because of this social repression and self-denial of natural expression.

Above the level of motor periodic responses which may afford a favorable background for temporal and intensive judgments there are direct rhythmic responses which may also be either explicit or implicit in their expression. These responses may take various forms, according to the mood or set of the individual. There may be a direct accompaniment to the objective pattern, in which each part of the action corresponds in time, intensity, quality, and relational value to a portion of the objective pattern. For instance, in the motor rhythm test, if done very simply, each tap on the fingers corresponds to one of the sounds in the pattern,

[12] The writer favors *McDougall's* (12) point of view that rhythm is essentially an impression, rather than a reflected consideration.

and the movement of the fingers between taps is an expression of the relation of the parts to the pattern as a whole.

By the process of "analytic projection," secondary or tertiary patterns, similar to the overtones of a sound wave, or to the component tones of a consonant chord, may be superimposed upon a primary rhythm, and any one or all three may be expressed either incipiently or overtly at the same time in the form of syncopation, as emphasized by *Stetson* (23) and *Patterson* (15).

The writer is inclined to emphasize the semi-voluntary and voluntary musculature, in their reconstitution of the stimulus through proprioceptive stimulation. Whereas the periodic background of set rates of pendular action can afford at most only a sort of "filled time" basis for the impression of regularity in rhythm, the incipient rhythmic response of the semi-voluntary or voluntary musculature goes much beyond this in being adaptable to the individuality of any pattern or rate of presentation. The incipient stages of this resonant rhythmic response are perceived as mixed auditory and kinesthetic imagery, which may become explicit in the repeated overt action appropriate to the specific rhythm pattern.

Analysis of sense of rhythm. In the statistical treatment of the results of experiments in Series I, separate analyses are afforded of motor rhythm and the sense of rhythm, or rhythm perception. The zero order of correlation of various tests with the sense of rhythm are as follows (from Table II):

		P.E.
Motor Rhythm 50 r.p.m.	.64	.06
Motor Rhythm 40 r.p.m.	.54	.07
Tonal Memory	.56	.07
Sense of Time[1]	.52	.07
Sense of Pitch	.32	.09
Memory Span (digits)	.44	.08
Pursuit	.22	.10
Steadiness Tracing	—.12	.10
Thrust Precision	.22	.10
Motility	.10	.10
Reaction-time	.17	.10

From our knowledge of factors involved in the motor rhythm test, as shown by partial correlations, these tests may be grouped

[1] This value of r is probably more reliable than the others previously quoted, since it represents individual retesting.

into those measuring " basic rhythm," kinesthetic memory, general muscular coördination, and speed factors. Of these, the most important factor seems to be kinesthetic memory, since that includes one aspect of all four of the Seashore measures and memory span as well as motor rhythm. Since " basic rhythm " is probably a form of the kinesthetic memory, the test is fairly homogeneous. Memory span has but slight significance in itself, aside from its relation to the sense of rhythm through the common factor of general kinesthetic memory. Muscular coördination and speed of reaction are of very slight importance.

Tonal memory is related to sense of rhythm chiefly through this factor of kinesthetic memory, but to a slight extent through its subjective approximation to " basic rhythm " which may be in part facility in subjective grouping through vividness of the balanced deviations. The sense of time is of less importance in the same way.

Other cognitive and motor factors. After the analysis of the main features of the series, the motor rhythm and sense of rhythm tests, there still remains a number of other capacities on which we have new data. As predicted by *Thorndike* (26) there is at least a slight positive correlation between all the capacities measured by these psychophysical tests, with one exception, that of steadiness tracing *vs.* sense of rhythm, and that not significant. Since chance would make 50 per cent of insignificant correlations negative, this constant positive trend must be interpreted as meaning that each of the capacities have some factor in common with all the rest, which is postulated to be the degree of capacity for intensive concentration, a form of sensori-motor coördination, or perhaps merely a vague selective effect in the preservation of strains which have slight advantage in general sensori-motor coördination.

From the low correlations between the three measures of muscular coördination, namely, pursuit, steadiness tracing, and thrust precision, it is inferred that general muscular coördination is a rather heterogeneous capacity, which might perhaps be measured by a collective test of diverse factors in which each test con-

tributes a moderate amount of correlation with the whole, as in general intelligence tests. The lack of standardization in motor tests, except for a few, such as the motor rhythm test and the pursuit and motility tests, suggests the advisability of constructing and standardizing new and old tests, such as chain reaction and possibly some of the strength tests with comparison of right and left hand and foot action for diagnostic purpose of vocational guidance where skill in motor factors is of importance.

Likewise, memory is a heterogeneous capacity, with many special types springing from some common basis such as kinesthetic memory or ability to take and retain a motor set long enough to repeat the action or compare it with a second presentation. Some of the simpler tests, such as time and pitch discrimination, involve this capacity to a minor degree. The tonal memory and pitch tests are thus related through kinesthetic memory as well as in the ability to discriminate pitch differences.

The striking lack of correlation between the two speed tests, reaction-time and motility, throws some doubt on the practical significance of either for our present purpose. The simple reaction-time test may be too simple and artificial a situation, and should perhaps be supplanted by a chain reaction or other more practical form of test. The motility test may be criticized for the difficulty involved in distinguishing voluntary action from nervous tremor. Speed of tapping alone is not a sufficient index to general motor efficiency, as shown by the low correlations with other measures of general muscular coördination. It should, however, be of more importance where coördinated action is demanded at higher speeds.

In the selection of tests for diagnostic purposes it has been found that those involving liminal proficiency are not the best indicators of general capacity in that field, but rather, the best results are obtained by the use of other tests of supra-liminal proficiency in that field. For instance, ability in tonal memory cannot be predicted accurately from a knowledge of the observer's threshold for pitch discrimination, for other complicating factors enter into the situation. As another instance, reaction-time to

a single auditory stimulus is not a sufficient basis for prediction of skill in speed of tapping for a period of five seconds. The correlation of .10 is no greater than one P.E. and is therefore insignificant. With this in mind, the low correlations between some of the apparently related tests are seen in a new light. As an aid to consideration of specific correlation values, the following classification of the tests is suggested, bearing in mind that the distinction is in some cases only relative, and according to the dominant aspects.

Classification of tests on basis of emphasis on liminal or supra-liminal proficiency

Motor Rhythm	Supra-liminal proficiency
Seashore Measures	
Sense of Rhythm	Supra-liminal proficiency
Tonal Memory	Supra-liminal proficiency
Sense of Time	Liminal discrimination
Sense of Pitch	Liminal discrimination
Memory Span	Supra-liminal proficiency
Measures of Muscular Coördination	
Pursuit	Supra-liminal proficiency
Steadiness-Tracing	Mixed
Thrust Precision	Liminal proficiency
Measures of Speed	
Reaction-time	Liminal proficiency
Motility	Supra-liminal proficiency

Sensory limitations of motor rhythm. In a sensori-motor test, such as rhythm tapping, both the fineness of sensory discrimination and precision in muscular action may be limiting factors. The observer is aided in his rhythmic tapping not only by the fineness of discrimination between two nearly simultaneous sounds but also to some extent by his judgment of the interval between taps of the pattern. If the rhythm were repeated only a few times, this ability might be quite important. This judgment of consecutive intervals is shown in a rather simple form by the sense of time measure. The fact that this test did not correlate higher than the other sensory tests such as pitch may be explained on two grounds: First, the intervals in the rhythm test are repeated again and again so that even a poor observer may grasp them fairly well after a short time; and he is aided in doing so by the regular movement of his fingers in following a regulated pattern. Moreover, the consecutive intervals are not

judged separately but as progressive portions bound together by the swing of the whole rhythm. This might be called a " rhythmic reaction-time " or ability to hold a motor set with great regularity. Cues are derived from the sound just heard and those anticipated from past experience, aided by subvocal action with its valuable qualitative and intensive projections.

In addition to judgment of intervals there is a second temporal factor, namely, the fusion threshold of two simple sounds, which is involved in the motor rhythm test. A series of three experiments was designed to measure this threshold under ideal and working conditions. In the first experiment two clicks were sounded from a low and a high pitch telephone receiver at intervals at from .06 to .0025 sec. and the observers were required to determine whether the " bass " sound came first or second. Proceeding according to the method of constant stimuli the threshold was determined for 75 per cent of correct judgments. The twelve observers tested showed thresholds ranging from .015 sec. to less than .0025 sec., the limit of the apparatus. The average threshold was .006 sec. deviation on either side of the standard.

For this fusion test the graphic apparatus was removed from the rhythm chronograph and a duplicate turntable placed in an inverted position upon the regular one. The turntables had each one silver contact point upon its circumference and were separately connected in circuits with differently pitched telephone receivers. By changing the relative position of the two silver point contacts the clicks could be sounded together or consecutively at an interval of some thousands of a second. As a practice trial the receivers were sounded separately and then consecutively at an interval of .06 second, enabling the observer to become familiar with the method to be pursued. After a signal, each pair of sounds was produced twice and the results announced at the end of ten trials.

Working with the same apparatus and method as for the discrimination of a single pair of sounds, sixteen people were tested for discrimination of pairs of sounds in the rhythm pattern which

was used for the motor rhythm test. This pattern consists of an eighth note, two quarter notes, and a dotted quarter note. The threshold under these conditions ranged from .004 sec. to .35 sec., with an average of .014 sec., or more than twice the interval necessary for the discrimination of a single pair of sounds. This may be attributed to the fact that the larger number of sounds coming close together in the rhythm pattern was slightly confusing. There was a tendency to judge the whole by the first and last notes of the pattern. There is a slight practice effect in this test, most observers having a cognitive threshold of .04 to .06 sec., which is steadily lowered until at the end of thirty trials, or about the number of practice rounds in the motor rhythm tests, the threshold is about .025 sec. and continues to drop until the real or sensory threshold is reached.

Following the two sensory tests of the fusion threshold for sounds, in single pairs and in rhythm patterns of pairs of sounds, a measure still more applicable to analysis of sensory limitations of the motor rhythm test was devised. The observers, each of whom had just completed the regular three trials of the motor rhythm test, were instructed to tap about fifteen to twenty rounds of the motor rhythm pattern as usual in the test, and then to stop as soon as they had tapped one round which seemed to be exactly synchronous with the regulated pattern.

In these tests, the results of twenty-two trials, by four observers, are reported as the range and average values for each of three criteria, as follows: (1) Average deviation calculated from the exact point at which each tap should have occurred during a single round of the pattern: range of scores, .006 sec. to 0.42 sec., with average of .017 sec.; (2) the constant error by which the observer anticipated or delayed his tapping of the pattern as a whole: range of scores, —.003 to —.042 sec., with average of 1.5 sec.; and (3) the average deviation calculated from the basis of the constant error rather than from the positions at which they should have occurred: range of scores, .003 to 2.3 sec., with average of .009 sec. The scores on the regular motor rhythm

test, made just previous to the " satisfaction " test, averaged .024 sec. for standard deviation and .019 sec. for constant error.

Comparing the average deviation about the constant error on " satisfaction " test with the standard deviation on the regular motor rhythm test with allowance for the difference between the measures of A.D. and S.D., we find that scores on the rhythm test are more than twice as large as those which were adjudged satisfactory for one round. Taking the most stringent measure of satisfaction, that of the average deviation about the exact points at which each tap should have occurred, there is found a closer approximation to the degree of regularity of the standard motor rhythm test, but it should be remembered that the S.D. of the motor rhythm test would also be higher if calculated from the exact positions instead of from the constant error. The ratio of variability in " satisfaction " test to that of the motor rhythm test is approximately 1 to 2. Since the fusion threshold accounts for roughly only one-half of the variability of the actual test, the remaining variability must be ascribed to the factors of ear-hand coördination and the variability of the muscular action itself.

Subjective aspects of motor rhythm. Subjective rhythm is of great general importance in the field of rhythm as a whole, for it may be experienced without a direct objective basis, but objective rhythm always implies a subjective aspect. Subjective rhythm itself is not a simple thing and ranges from the simplest temporal or accentual grouping of the periodic ticking of a clock of which we are scarcely aware, up through conscious projection of complex rhythmic grouping and accentuation, and of qualitative meaning upon simpler patterns, to the interpolation of secondary and tertiary rhythms, and syncopation of these experiences into intricate rhythmic action of the whole body.

If a subjective rhythm pattern is perceived from what is objectively only a periodicity, without recognition of its simpler nature, the experience is one of illusion. From this extreme, the subjective aspect may be partially or wholly recognized by the observer as a conscious projection, or perhaps as an aggressive background upon which the sensori-stimuli impinge and are interpreted in

their perception and appreciation. Always, though, there is something of the nature of an illusion in the experience of subjective rhythm.

In its simplest forms, as in the repetition of the nonsense syllable "mi" by the young children studied in *Squire* (25), the subjective rhythm first showed itself as a temporal grouping of syllables into twos, or spondees. Later and less frequently an intensive accent was used to make the grouping iambic.

Among the older children and adults studied in this research, the subjective rhythm was more highly developed, and one of the usual experiences of the observers on the rhythm tests was the accompaniment or substitution of intensive for temporal values, and likewise of temporal and qualitative effects with intensity or stress. The two were so closely bound up that the nature of the illusion was not realized until it was called to their attention that the intensity of the pattern of the motor rhythm test is the same all the way through. This association and confusion of different aspects was found to extend to qualitative deviations, which were used as an aid to grouping. This may range from a simple perception of the pattern as "tee dum tah dah," in which only the vowel sounds are changed, up to the subjective accompaniment of an entire melody while tapping in the motor rhythm test. The best score on the test was made by a musician who reported that he had interpreted the simple four-click pattern as the highly rhythmic Spanish melody, "Habanera," from Bizet's opera, "Carmen." One of the highest scorers among the women also reported this same melodic association, and when it was suggested to others after finishing the test they were quick to see its possibilities.

The grouping of rhythm patterns by accent or qualitative differences may, however, affect the temporal regularity adversely by undue alterations in the pattern. This is a fault of inexperienced musicians; but when it is very slight and well balanced, as in the performances of persons with good sensory and motor rhythmic abilities, the benefits of the illusion outweigh its defects and add to the artistic effect.

It follows from the nature of subjective rhythm that no particular subjective pattern must necessarily be associated with each particular objective periodicity or rhythm. In general it is probable that the simpler the objective stimuli, the greater freedom will they afford in subjective grouping; as, for instance, almost any tune can be projected upon the ticking of a clock, but relatively few would fit the four-click pattern of the motor rhythm test. It is possible to group this in four different ways; musically the four possible groupings might be written: 1. Eighth note, two quarter notes, and a dotted quarter note. 2. Quarter note, dotted quarter note, eighth note, and quarter note. 3. Dotted quarter note, eighth note, and two quarter notes. 4. Two quarter notes, dotted quarter note, and eighth note. But there is a distinct order of preference among these ways, and the last two of them are scarcely used at all, while the second is also rare.

The first grouping is the one nearly always used, and the experimenter distinctly remembers that when first starting on the motor rhythm test there was a sort of " reversible perspective " illusion between the first two patterns. By direction of attention from one or the other grouping, the sounds could be perceived in either way; but, after working with the pattern for several months, it became practically impossible to perceive the sounds in the second grouping, except at a very slow speed, at which the swing of the rhythm is not so strong a factor and the sounds can be perceived on a more individual basis. Even under these conditions, the second grouping seemed forced and unnatural.

A number of observers reported spontaneously that they could group the sounds in either of these two ways, and one observer, an instructor in vocal music, reported the third grouping, but upon comparing notes afterward with the experimenter, preferred the first grouping as better balanced. This seems to verify *Woodrow's* (30) interpretation of the ending effect of long intervals and beginning effect of short intervals. Likewise, the fact that the last note was often subjectively accented would super-

impose another ending effect of intensity upon that of the longer interval.

The second or last notes were most often accented, with some preference for the main accent upon the second, with a less accent upon the last note. No observer reported the fourth possible grouping, and an attempt to produce the pattern in that grouping will be found very difficult. This preference for certain groupings seems to fall in line with the Gestalt theory of perception by configurations, as stated by *Koehler* (7) and *Koffka* (9), with certain configurations more probable than others due to either innate or acquired influences. The observations of *Lanier* (11) and *Squire* (25) on the predominance of iambic rhythm in great poems of the English language may be another instance in point. Even in prose rhythm there may well be certain preferred groupings which are basic types, because of their superior balance and grouping effects of time, intensity, and quality.

Other possible tests of time and rhythm. In the studies made in the Iowa Psychological Laboratory on rhythm and time, the temporal aspects have usually been in terms of intervals between sounds rather than duration of sounds. Both interval and duration are involved in the rhythms of music and literature, and the distinction is more logical than psychological, for they are most often closely bound up one with the other. It is found that the fifth grade children substituted duration for interval on the motor rhythm test by holding each tap until just before making the next, although they had been instructed and shown how to tap very short sounds with intervals. Also, when called to their attention, they had trouble in changing. Eighth grade children were somewhat freer in their interpretation of interval *vs.* duration, but at this level there were still some children who could not dissociate the two. At the adult level, most of the observers could tap either way, but there were a few who found the distinction very difficult, even when demonstrated to them. Among the superior musicians the rhythm pattern was usually interpreted in terms of

intervals, between very short sounds, as it was actually presented to them in the objective rhythm pattern on the telephone receiver.

There is a possibility of the construction of time and rhythm tests on the basis of differences in duration, and some psychologists and musicians think that this might be more representative of the actual conditions of music and literature. It is, however, very easy to project duration upon short sounds in the same proportion as the interval which actually followed it in the objective pattern.

A distinction similar to that between interval and duration is the one of tests involving liminal discrimination or proficiency *vs.* those measuring proficiency at a supra-liminal level, as discussed above.

It has also been urged that a rhythm test should involve not only temporal and intensive differences but also variations in quality, as being more representative of rhythm as a whole. A somewhat parallel case is that of the measures of pitch and tonal memory, in which there is found a correlation of .60, P.E. .06, between the two. This relationship is not wholly due to the keenness of pitch discrimination, but also in part to the factor of kinesthetic memory, which is common to both, though only slightly involved in pitch. Tonal memory is found to correlate nearly as highly with sense of rhythm as with pitch and, if there were also temporal and intensive differences, the tonal memory test would become similar to the desired new form of rhythm test. Such a test might be a better measure of ability to perceive rhythms as they occur in music, or to a less extent in verse, but it should lessen the effect of subjective rhythmization.

The great advantage of the *Seashore* (20) measures of musical talent is that they are sufficiently independent to permit the diagnosis of individual strong and weak points in musical talent as a whole. Thus a person might fail or make a low score on a composite test of musical ability through inability to handle the factor of pitch, but without the special measures all that would be known would be that he had failed. There is likewise some

danger of the influence of differences in training in the rating of talent by a composite test.

Motor rhythm test; automatic counter method. A second method of giving the motor rhythm test has been devised, differing from the graphic method chiefly in the recording mechanism. In order to avoid the work involved in scoring of graphic records in the motor rhythm test a new apparatus (Fig. 3) was designed

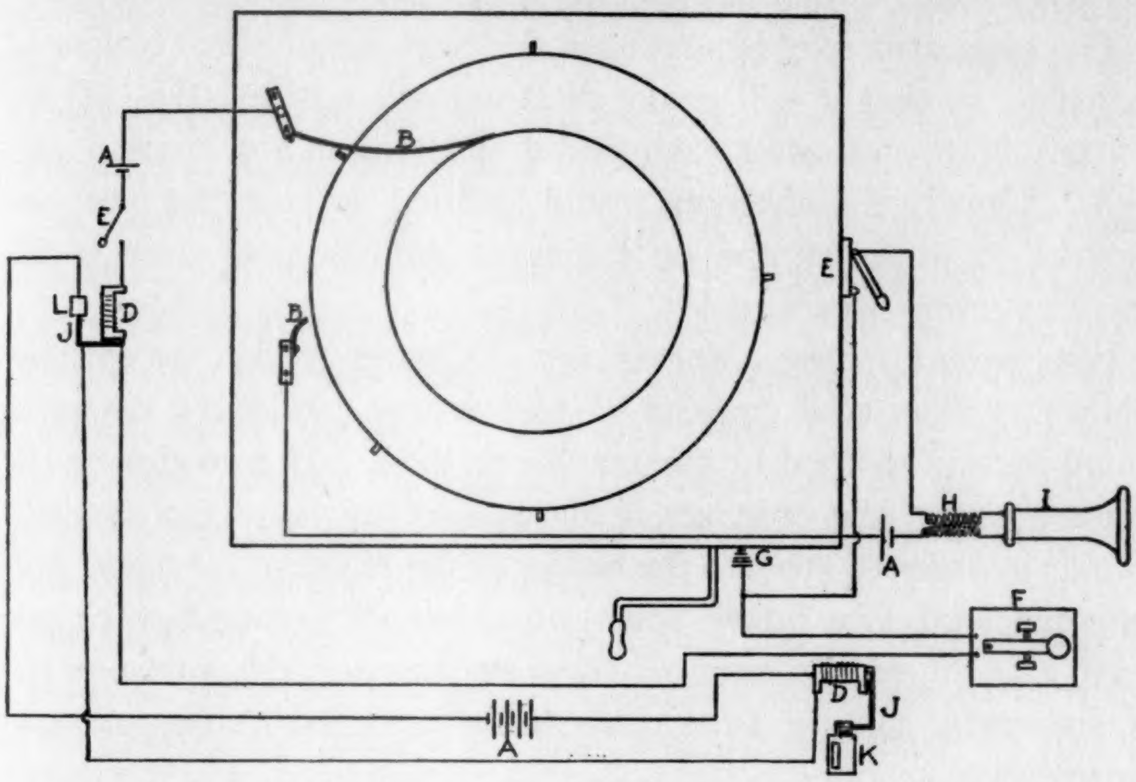

Fig. 3. Automatic counter apparatus for motor rhythm

to count automatically the number of taps in a pattern which fell within certain limits before and after the sound stimulus occurred. The chronograph was arranged as before in the graphic method so as to produce the same rhythm pattern in the telephone receiver (I). In place of the graphic recording device, a wooden disc ten inches in diameter and two inches thick was placed on the turntable. Embedded in the edge of the disc are three silver plate contacts which pass under a brush (upper B) for durations of .03, .06, and .12 secs., respectively, according to the set of plates being used.

A specially designed telegraph key (F) is so constructed that it gives only one almost instantaneous contact on the down stroke

of the key and none on the return stroke. This is in circuit with two dry cells (A) and the wooden disc target arrangement so that, if the key is tapped within .06 second before or after a sound in the rhythm pattern, it will complete the circuit through a relay magnet (D, J, L). An electric counter (K), consisting of a large magnet actuating a Veeder counter, is wired in circuit with four dry cells (A), the circuit being opened and closed once by each stroke of the relay magnet at the mercury contact (L).

The apparatus may be arranged for any one of three orders of difficulty, so that it will count all taps made within .015, .03, or .06 sec. before or after each sound stimulus in the rhythm pattern. Usually the observer would be tried only on the first two degrees of difficulty and on the most difficult ones only if his previous scores warranted it.

Instructions to the observer are the same as for the graphic method. Each trial consists of twenty-five rounds of the same sound pattern as used in the graphic method. Before closing the counter circuit the observer is allowed to tap from five to eight rounds in order to get into the swing of the rhythm. After a preliminary trial four more trials of twenty-five rounds each are given and the results read off from the counter, the total number of successful taps in four trials being recorded as the score in the test.

Since this apparatus was not completely adapted for use in time for this research no norms are as yet available. It has the advantage of simplicity and direct reading; but it fails to take account of the constant error of the individual, except indirectly, as that should be minimized by the experimenters being able to call attention to it and give practice in correcting. This shortcoming of this type of apparatus really disqualified it for the present purpose.

Rhythm learning test. In a study of ability in perception of rhythm in its relation to ability for learning longer patterns, a new test was devised, involving rhythms varying only in length of interval between simple sounds of two different intensities. The patterns used were those described by *Revesz* (17) but the

apparatus and method were devised by Seashore. The sound producing apparatus consists of a revolving disc driven by a phonograph used as a spring motor and studded with twelve concentric rows of brass contacts, each row of contacts being spaced to produce a different rhythm pattern. To secure unaccented and accented sounds their respective contacts were wired in two different circuits and the unaccented circuit run through resistance before reaching the telegraph key which produced both types of sounds. The telegraph key is deadened with rubber on one side so as to produce only single clicks. A telephone receiver would answer the same purpose.

The patterns consist of series of loud and soft clicks from nine to thirty in number in each pattern and with spacing between the clicks which corresponds to that in musical measures. The patterns each have within them three groups which may or may not have been varied slightly; where they differ, the one which has been changed, usually the first one, has been offset by the opposite change in the last two. There are not more than one or two clicks difference in any one pattern.

The observer was shown the apparatus and the way in which it worked. He was then asked to sit in an adjoining room with the telegraph instrument at his hand and, upon hearing the signal "ready," listened to the rhythm pattern until the signal "go" was given, at which he was asked to tap out the rhythm pattern, using a pencil-shaped stick, upon the arm of the chair. The number of times that each pattern had to be repeated in order to be reproduced correctly was recorded for each test, and the total for twelve tests was taken as the score. After finishing the test the observer was questioned as to his devices for remembering the pattern, the types of his sensations, and any previous training which might have aided him in this line.

The observers for this series were thirteen of the highest and an equal number of the lowest scorers in the Seashore sense of rhythm tests which were given to the elementary psychology class at the State University of Iowa. The following table gives the individual scores on the various tests:

Table VI. *Scores of rhythm learning test and Seashore measure of musical talent*

Observer	Rhythm learning	Rhythm perception	Tonal memory	Time	Intensity	Pitch
1..........	47	1	25	32	16	0
2..........	47	0	2	54	66	0
3..........	48	4	6	0	14	8
4..........	46	1	13	9	82	15
5..........	36	7	14	2	10	59
6..........	36	1	8	54	74	70
7..........	48	4	23	13	3	32
8..........	36	4	34	16	34	21
9..........	35	1	6	16	16	3
10..........	37	0	1	13	39	9
11..........	48	0	37	2	29	22
12..........	34	4	32	4	29	40
13..........	43	2	19	4	82	15
1..........	22	97	93	32	87	76
2..........	19	94	99	87	87	3
3..........	19	98	98	54	82	91
4..........	25	98	100	98	19	26
5..........	24	96	95	78	25	63
6..........	25	94	98	78	92	76
7..........	22	99	71	83	66	81
8..........	24	94	91	54	34	63
9..........	45	98	29	61	74	26
10..........	27	94	93	73	51	76
11..........	25	91	89	54	58	81
12..........	19	98	97	87	92	56
13..........	73	99	93	11	82	81

Correlations between the most important scores are as follows:

Sense of rhythm vs.	Learning rhythms	r	.83	P.E.	.02
Sense of time	Learning rhythms	r	.61	"	.04
Tonal memory	Learning rhythms	r	.87	"	.02
Tonal memory	Sense of rhythm	r	.91	"	.02

It should be understood that these values are considerably enlarged by the fact that they are taken only on extreme cases, which give most of the value to an ordinary unselected correlation. The fact that tonal memory correlates so highly with sense of rhythm should be balanced by the fact that for this range of talent the rhythm test itself would have a still higher reliability, probably about .98, and it will be seen from the table of predictive value of r (Table III) that this rise is very significant.

From the close relation between perception and learning of rhythm patterns, it is seen that the test is valid in the selection of

that particular capacity in musical talent, and that a person who is able to grasp rhythm patterns easily can also learn longer rhythms with facility.

Practice effects. It was found that three trials usually showed a plateau in the curve of progress in the motor rhythm test; and, when there was evidence of any considerable improvement from the second to third trials, a fourth trial was given, and succeeding trials were usually no better than that. The average raw score on the motor rhythm test of all the adult observers except failures was .029 sec. for both the second and third trials, which shows that either trial is very close to the true attainment. Moreover, with some short preliminary practice, the first trial was in a few cases slightly better than the second or third. Since some slight further progress with more extended practice would be expected, the best of the three trials was taken as the score. It correlated slightly higher with other criteria and should theoretically be closer to the average score after practice. The following experiment on practice effects takes further account of the validity of the procedure.

To determine the improvability of the individual capacities for motor rhythm, five observers were tested for six successive days on the same motor rhythm test. These persons were selected at random and without any definite knowledge of their rhythmic capacities. Following the usual method of scoring, the best of three trials on the first day was taken as an individual measure in terms of raw score and the equivalent percentile rank. On the succeeding days, a short warming-up period took the place of the usual first trial and only two trials were given on each of these days. The observers were told of their progress and minor faults, as in the regular test procedure.

The scores on the first day ranged from 17 per cent to 90 per cent. A comparison of scores on first day with average of all days showed a range of improvement of from —5 per cent to +21 per cent, with an average of +5 per cent. Comparing the first day with best succeeding trial showed a range of improvement of from 10 per cent to 40 per cent, with an average of 22

per cent. The average of the six days seems to be the best criterion, because the observers were not able to keep consistently up to the high level of the best score for the longer period.

This slight improvability in motor rhythm fits in well with Miss *Klaver's*[13] findings on improvability of sensory rhythm capacity as measured by the Seashore test. Two months of intensive training of all sorts—marching, clapping, beating time, listening, etc.—failed to show a significant rise in the average of the group.

Free vs. regulated rhythmic action. Investigations of free motor rhythm have as a usual thing been too elementary to make accurate judgments of the ability in handling longer patterns of the true rhythmic type. Many experiments on free rhythm are really only on periodicity, and in our study we have found it necessary to distinguish between liminal and supra-liminal proficiency. Of the recent works on free rhythm that of *Stetson* (24) is an interesting example. Having observers tap an eighth note and dotted quarter in succession, the relative durations were measured upon a kymograph drum and compared to the ratio of 1 to 3 which should theoretically exist. Working with six trained pianists, he found that results varied all the way from a proportion of 1 to 2 to that of 2 to 3; that these performances were adjudged satisfactory by the musician at the time of making them; and that, while the same individual was fairly consistent for any one short experimental period, he was not consistent from day to day; and the performances of the six pianists did not agree with one another in any regular fashion.

This shows that artistic deviations may be considerable and yet be felt as satisfactory. *Metfessel* (13) has found that singers take very great freedom with rhythm and the specific time values of notes. This probably is mainly in the interest of interpretation of content, but as Stetson has shown, may be due in a large part to inaccuracy of time concepts under sensory control. There may be deviations, but they must not be haphazard, as would be

[13] Summarized by *Kwalwasser* (11).

caused by poor muscular coördination. It is this muscular coördination which is measured by the motor rhythm test.

In a brief experiment on partially regulated rhythm on the graphic rhythm chronograph apparatus, it was found that if the observer be allowed to tap in time with a standard pattern for say thirty repetitions of the pattern, and then continue tapping in the same way after the sound stimulus has stopped, he will almost immediately change his rate, but show about the same amount of variability ahead or behind this changing standard, tending to become less regular as the time goes on. Moreover, the highest scorer on the regulated motor rhythm test did relatively no better than several average observers under these conditions. The experimenter himself, having heard the pattern thousands of times at the same rate, was unable to do any better than the others.

We have already mentioned the apparent regularity of free rhythmic action and the fact that sensory knowledge alone is not sufficient in scores on the "satisfaction" test as compared with the actual regularity in motor rhythm over a longer period of time. The observers at times realized that they were slightly ahead or behind, but could not immediately or exactly correct this, nor could they maintain the motor regularity when once attained. General motor coördination is an important factor in a special sensori-motor test.

In the substitutional qualities of interval, duration, intensity, and qualitative aspects, we may have another clue to the muscular basis of rhythm. Why should they not be confused when they are represented in action by the same movements of the same musculature, as in singing or playing an instrument? This may be integral with, or an accompaniment of, the Gestalt type of perception by configurations.

Validity of motor rhythm test. The field of musical performance offers a good criterion of the validity of the miniature sampling of rhythmic action afforded by the motor rhythm test. In the selection of a representative group of musicians, eleven were picked as being among the best of the university students tested, and four were recommended from the musical organiza-

tion of the North Des Moines High School by their director of music, who was familiar with the test. The group of fifteen is listed below in Table VII with their percentile ranks in regularity, their constant errors, and a brief description of their particular field of music:

TABLE VII. *Percentile ranks and constant errors of fifteen superior university and high school musicians on motor rhythm test*

Observer	%	C.E.	Field of music
1........	100	—.4	Director of large high school glee clubs, orchestra and band. Versatile in music
2........	97	—.7	Violinist, won second place in state high school contest
3........	60	1.4	Kettle drummer in university orchestra; scored high in all of Series I tests
4........	70	1.5	Drummer in university orchestra; rated high on other tests of Series I
5........	98	—.3	Girls' glee club, high school
6........	70	—.1	Men's glee club, university
7........	90	2.3	Violinist in the university
8........	82	1.3	Pianist studying music supervision in college
9........	90	4.7	Advanced student in piano; instructor in college music department
10........	90	3.0	Violinist, university orchestra
11........	95	1.3	Graduate student pianist in university
12........	50	—.1	University men's glee club and band; several brass instruments
13........	97	1.9	High school glee club, violinist (colored)
14........	100	1.8	Pianist in high school; comes from family of musicians
15........	75	—.1	Pianist playing with dance orchestras
Average..	84.3	±.6 or —.47	

These data are not sufficient bases for statistical treatment, but the range of scores, from fiftieth to the hundredth percentiles, and the average rank of 83 per cent for the group indicates that motor rhythmic ability as measured in this test is essential to musical proficiency. It is understood, of course, that these musicians are not all of equal rank in musicianship as a whole, and that the selection was made by a non-musician. Moreover, sensory or vocal qualities may be sufficient to balance deficiencies in other fields. Again, it may be that average motor rhythmic ability may be satisfactory for amateur musicianship.

There is immediately the question, Will not musicians have an advantage over non-musicians by reason of their training? Two

answers may be given: First, muscular action of any sort probably helps in the development of motor coördination, but if musical training were of great importance, then those persons who have had it should rank significantly higher than those who have had no special practice. That this is not true is shown by the low percentile ranks and even failure of a considerable number of persons who have had several years of musical training. Moreover, nearly every child has had some piano lessons at least, and this training is often given and continued with scarcely any regard for their ability to make use of it; sometimes it may be in the hope that low abilities may be improved by training. Secondly, some of the very highest scorers on the test, equaling the best musicians in this capacity, have had no special musical training at all, even though they possessed considerable latent talent and were of superior intelligence.

Likewise general intelligence is not an influential factor in the sense of rhythm, at least for the range of talent found in the university. A correlation of percentile rank of forty-seven men on the University of Iowa qualifying examination with rank in the sense of rhythm showed a coefficient of correlation of .10, P.E. .09, which is not significant. This is rather to be expected, since the sense of rhythm was not very highly correlated with memory span for digits, one of the usual types of memory items in intelligence tests, and similarly, the directions of the rhythm test are so simple and well illustrated before starting as to make but slight demands upon the student's ability in comprehension.

The conditions of measurement in the test are adapted to various levels, without undue influence of other capacities. In the matter of optimum speeds, it was found that adults did equally well at 40 and 50 r.p.m., but that 60 r.p.m. was too fast for some observers and 30 r.p.m. seemed too slow and monotonous for most adults. Correlations of motility with scores on motor rhythm showed a barely significant relationship at 50 r.p.m., but none at 40 r.p.m Since the purpose of the test is to measure motor rhythm independently of other factors, there was a slight advan-

tage in favor of 40 r.p.m. For these reasons, the speed of 40 r.p.m. was adopted for standardization.

Experimentation with eighth grade children showed that they likewise were best able to perform at 40 r.p.m., but some were bothered by a faster speed, and as with the adults, 30 r.p.m. was too slow to give the same degree of easy swing or balance in the action. Thirty r.p.m. was found to be adapted to the degree of development of fifth grade children. Only the best could make even a respectable showing at 40 r.p.m.

The same test is thus adaptable to different levels of motor development, and may be given for diagnostic purposes while the young students are still in their training stages.

The high scores of musicians shows that this test of *regulated* rhythm is closely related to ability in free rhythm as employed in individual action, and the simplicity of recording and scoring the performances in the regulated rhythm test give it a great advantage over a test of free rhythm. Moreover, the tapping in time with a regulated pattern is directly applicable to ensemble and directed group work which is a large field in music and other forms of rhythmic action.

Reliability of motor rhythm test. The reliability of the motor rhythm test at 40 r.p.m. was calculated from the first *vs.* the second trials of the two best trials each of 135 adults, and the coefficient of correlation found to be .80, P.E. .02. Since this corresponds to $r\frac{1}{2}, \frac{1}{2}$, the reliability of one-half the test against the other half, the values were treated by Brown's formula for twice the length of the test, to give the coefficient of reliability for the best of three trials against best of three later trials, as for the actual length of test used as the individual's score. The value of r is in this way found to be .89. This shows that the test is sufficiently reliable for predictive use.

Since there are but three trials, lasting for one minute each, neither monotony nor fatigue are appreciable, and the tendency towards automatism is merely a drifting into the efficient form of secondary passive attention. The spirit of achievement and

competition served as a constant incentive for the observers to do their best.

In presentation and scoring the construction of the test is such as to make it relatively easy to handle and objective of interpretation. It may be given by a person not versed in laboratory psychology if he is able to follow simple directions, as is shown by the fact that children readily grasp the essentials of the test and several high school boys have given it. It would be profitable to have the apparatus available for free use in the schools.

Constant error. The factor of the constant error of anticipation or delay of response must be separated from that of regularity for a number of reasons. First, there is practically no correlation between the two. On the forty-four observers of the first series at the speed of 40 r.p.m, the correlation between C.E. and the standard deviation, the measure of regularity, is only .37 with a probable error of .09, which makes it just barely significant. At this speed there is a tendency for observers to anticipate, but this is not regular and changes from one trial to the next, nearly always in amount and often in direction, being a temporary set or subjective viewpoint where it is large enough to be significant. At 50 r.p.m. there is no such tendency. Furthermore, as happened in several cases, the tapping may be quite regular, but considerably anticipated all the way through the test. Also, being a regulated rhythm, the constant error should be of little importance in free rhythm, and it is thus better to measure the factor of regularity by itself.

Standardization of motor rhythm test. The apparatus, procedure, and results having been described, there remains only to establish a comparative scale for each of the various levels of motor development, which were chosen as the fifth and eighth grades for children and adults, in order to be directly comparable to the measures of musical talent. Only a small sampling of fifth grade talent was measured, and that only in order to show that the test is adaptable to that level, and that it shows a fairly wide distribution of talent. In terms of S.D., the measurement of regularity, these scores at 30 r.p.m. ranged from .026 to .065 sec.,

with a standard deviation of .010 sec. about the mean of .041 sec. At the eighth grade level, 113 children were tested from two junior high schools. They afforded a representative sampling of racial, social, and occupational groups. The entire eighth grade distribution is given in comparison with that of the adults on Table VIII.

The adult population consisted of advanced high school students, and high school teachers, and university graduates and

TABLE VIII. *Distribution of raw scores on motor rhythm test*

S.D.	Adults	Eighth grade
1.4—.5	1	
.6—.7	1	
.8—.9	9	
2.0—.1	14	
.2—.3	17	4
.4—.5	14	6
.6—.7	24	10
.8—.9	8	9
3.0—.1	12	12
.2—.3	8	17
.4—.5	4	12
.6—.7	7	11
.8—.9	2	3
4.0—.1	2	9
.2—.3		5
.4—.5	1	3
.6—.7	1	2
.8—.9	1	
5.0—	4	10

undergraduates, which included a fair proportion of amateur musicians and athletes. The distribution of these 130 adults is given in Table VIII.

Using the system of percentile ranks as a scale affording an easy and valid means for the comparison of motor rhythm scores within the test and with ratings on other tests, norms have been constructed for each significant step in the eighth grade and adult distributions. These are given in Table IX, from which it will be seen that both distributions are skewed in the direction of greater regularity. Cases of extremely poor coördination are fewer in the adult population than in the eighth grade, which may tend to show that even the poorest cases make a partial recovery as they grow older, although the selected nature of the adult

group, chiefly of university students, may invalidate this hypothesis.

Summary. A measure of temporal precision in rhythmic auditory motor coördination has been developed and standardized for eighth grade children and adults, as an index to individual success and ability to profit by training in rhythmic action such as musical

TABLE IX. *Table for conversion of raw scores into percentile ranks on motor rhythm test*

Adults score	Eighth grade score	Percentile rank
Total failure	Total failure	0
4.7	wrong pattern	5
3.7	4.8	10
3.4	4.3	15
3.2	4.1	20
3.1	3.9	25
3.0	3.7	30
2.7	3.5	40
2.63	3.3	50
2.5	3.2	60
2.3	3.0	70
2.23	2.9	75
2.14	2.8	80
2.0	2.6	90
1.9	2.5	95
1.6	2.2	100

performance. In this investigation it is found that the liminal discrimination of small intervals of sound is of less importance to rhythm than the supra-liminal proficiency in taking and retaining a muscular set of the pattern as a whole for a sufficient length of time to reproduce it or compare it with a second presentation.

The apparatus for the motor rhythm test is an adaptation of the Seashore phonograph chronograph with a telephone receiver circuit for the production of the sound pattern, and a telegraph key and graphic recording device of a magnetically operated fountain pen which makes spiral tracings on a disc of glossy paper rotated on the phonograph turntable.

By a statistical treatment of tests of perception of rhythm, motor rhythm, and ten diverse psychophysical tests it was found that motor rhythm involves a factor which may be called " basic rhythm," since it cannot be partialed out by comparison with related tests and is inherent in measures of rhythm. The most

general factor is that of "kinesthetic memory," or the ability to apprehend and retain a motor set long enough to repeat or compare the action with a second presentation. This is common to the two rhythm tests, tonal memory, sense of time, sense of pitch, and memory span for digits. A third factor of importance to motor rhythm is "general muscular coördination." Neither speed of tapping nor reaction time are significant for precision of motor rhythm.

In the perception of rhythm as measured by the sense of rhythm tests, the factors of basic rhythm and that of kinesthetic memory are again dominant. Simple memory span in itself is of little importance to the sense of rhythm. Factors of general intelligence, general muscular coördination, and speed are not significantly correlated with perception of rhythm.

A group of superior amateur musicians showed a high average rank, but scores on the test are found to be very slightly affected by training in music or continued practice on the test itself. These facts point in the direction of validity and elemental nature of the test.

The test has a reliability coefficient of .89, P.E. .02. It is adaptable to adults and children in and above the fifth grade, and norms have been constructed for the eighth grade and adult levels. In general, this measure of motor rhythmic coördination seems to comply with the demands upon a test of one of the basic motor capacities.

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THE RELATION BETWEEN MUSICAL CAPACITY AND PERFORMANCE

BY

FLORA MERCER BRENNAN

Capacity tests: method of selecting the students, apparatus, method of giving the tests, supplementary data; performance tests: instructions to the selected students, conditions under which the performance was given, the judges, method of rating performances, performance rating blank; analysis of factors involved: variable elements from the standpoint of the performer; talent charts, performance ratings, and musical training; comparison of capacity and performance ratings: division of capacity tests into sensory and motor groups, method of ranking the capacity tests, of ranking the performance ratings, evaluation of the performance ratings, distribution of marks, agreement among the judgments, intercorrelation of the five criteria, validity of the judgments, correlation of each criterion with the capacity tests, relation of individual capacity tests to performance, time in performance, tone-quality, intensity, artistic unity, negative correlations; relation of training to performance: correlations of training with performance and capacity, problems suggested; summary, conclusions, and recommendations; bibliography.

The purpose of this study is three-fold: (1) to establish procedure for the investigation of relationships between musical capacity tests and musical performance; (2) to draw tentative conclusions regarding the existence of such relationships; and (3) to suggest subsequent research in this field which will simplify and verify the results of this study.

Capacity Tests

For this investigation music students from the School of Music of the State University of Iowa were available. With the understanding that, since comparison of the various tests was the thing sought, it would be better to give a few students many tests than many students a few tests, twenty music students, ranging from the seventh grammar grade to the senior year in college, were chosen.[1]

[1] In a laboratory thoroughly interested in musical researches that have been carried on for a period of years under the guidance of Dr. Carl E. Seashore, a foundation for this study has been laid by all previous investigators in the

Method of selecting the students. The students were chosen by the director of the Music School in consultation with the writer. An effort was made to secure a group whose work would range from very poor to excellent in the director's estimation. Sixteen of the selected students played piano and four violin. In order to keep the group homogeneous, students of voice were eliminated, since the motor elements of their performance were not dependent on manual skill, as in the case of both violin and piano students.

The tests given were:

1. *Pitch discrimination:* the ability to discriminate between two tones whose frequencies differ in a series from .5 d.v. to 30 d.v., the constant tone of the two being a″, 435 d.v. (26)

2. *Intensity discrimination:* the ability to perceive the difference between the loudness of two tones, one of which is constant in intensity, the other differing from it by progressively smaller steps (26).

3. *Time discrimination:* the ability to differentiate between the duration of two time intervals, one of which is a constant, the other differing from it by intervals ranging from .2 to .02 seconds (26).

4. *The perception of consonance:* a judgment of the relative smoothness, blending, and purity of two tones sounded simultaneously in comparison with two other tones also sounded simultaneously (26).

5. *Tonal memory:* memory span for tone successions without melodic sense, the groups varying from two to six tones (26).

6. *Auditory imagery:* the ability to image tones without previous sensory stimulation (26).

field. The writer wishes to express deep gratitude to Dr. Mabel Clare Williams for her careful direction of this investigation, and to Dr. Warner Brown for his suggestive and detailed criticism of material. Grateful acknowledgment is also due Mr. H. D. LeBaron, Director of the School of Music at Ohio Wesleyan University, who suggested the problem, investigation for which was carried on during the year 1921–22. Acknowledgment must also be made to Dr. P. G. Clapp, Director of the Music School at the State University of Iowa, for his helpful and willing coöperation, and to the students whose interest and dependability were of untold aid in carrying on the series of tests.

7. *The control of intensity:* the ability to match a sound of given intensity (39).

8. *Pursuit:* the ability to learn to make a new eye-hand coördination, in which the subject tries to keep a flexible pointer in contact with a metal target revolving on a phonograph turntable (14).

9. *Motility:* a measurement of the speed with which the subject is able to make a simple tapping motion with a telegraph key during a five-second interval (19).

10. *Simple reaction:* a measurement of the simple reaction-time of the subject to an auditory stimulus (26).

11. *Serial action:* a complex reaction to a changing series of lights, each of which as a stimulus calls for an appropriate response-movement on a typewriter (11).

12. *Rhythm:* the imitation on the part of the subject of a series of rhythmic patterns which are tapped for him. The procedure is that devised by Geza Révész (21).

Apparatus. The tests of pitch, intensity, and time discrimination, the sense of consonance, and tonal memory were given by means of the phonograph records No. A–7536, A–7537, A–7538, A–7539, and A–7540, made by the Columbia Graphophone Company and described in their catalogues as the Seashore Measures of Musical Talent (25). The original records were made from apparatus devised and standardized in the Iowa laboratory (26).

The test of auditory imagery is the one described in *Seashore's* (26) "The Psychology of Musical Talent." The partial melodies were presented on the piano.

Since all of the motor tests are published in detail elsewhere, only the briefest description of them will be made here.

The apparatus for the voluntary control of intensity is a modification of the Seashore audiometer (39). There are thirty-five steps in intensity, determined by varying the number of turns in the secondary coil. The increments in sound are theoretically equally perceptible. The tone is produced by an electrically energized 100 v.d. tuning fork, which is connected with the primary

circuit. Two sliding contact riders, mounted one on either side of the contact points, vary the intensity of the sound, which is heard in a telephone receiver.

The pursuit apparatus is described as "a measure of capacity for acquiring skill in the coördination of eye and hand" (14). It consists essentially of a wooden disc stained black which carries a polished target and commutator, a flexible contact with the commutator, a Veeder counter operated by magnets, a control key, a 6 v. storage battery, a phonograph on which the wooden disc revolves, and a flexible pointer.

For the motility test (19), a telegraph key is put in circuit with a Veeder counter, and two dry cells. Shunted off from the control key of the Veedor counter is a metronome, carrying a small mercury cup. An arc of wire attached to, and oscillating with the pendulum of the metronome, enters and leaves the mercury. The pendulum is set so that the mercury contact is made just once in two seconds. The mercury contact is allowed to start the recording of the counter when tapping of the telegraph key begins; the counter key is closed for the second, third, and fourth second of the experiment; and when the counter key is lifted, the mercury contact terminates the experiment at the end of the fifth second. Thus an accurate five-second interval is secured, and the reaction-time of the experimenter eliminated.

The stimulus for the simple reaction test is a sound heard in a telephone receiver. The reaction-time was measured by a phonograph chronoscope (26).

The apparatus for the serial action experiment (11) consists of a commutator attached to a typewriter in such a manner that every movement of a key on the typewriter completes one of four possible circuits, the order of appearance being determined by chance for a series of seventy-five trials. In these four circuits are placed four lights as stimuli. Four keys of the typewriter, 5, 6, 7, 8, are associated with the stimuli, one key for each light. The subject places four fingers, the index and middle finger of each hand on these keys, and makes seventy-five successive reactions, in which each finger responds to its proper light

stimulus at such a speed as will yield approximately five errors a line.

While the rhythm test is that devised by Révész (21), the apparatus for giving it was invented by Seashore. In its present form, it consists of a revolving wooden disk, on which, in twelve concentric circles, the twelve rhythmic patterns are made by heads of brass. These are driven through the wood so that their distance from each other is in proportion to the time-values of the notes which they represent. The simpler patterns are in the center of the disk, the more difficult ones on the periphery. Each pattern is repeated three times. On the under side of the disk the contact tacks representing the unaccented beats are connected to form one circuit, while the accented beats form another. A flexible contact, which may be adjusted radially along the disk, rides over the contact points. The disk is driven by a belt attached to a phonograph turn-table. The speed is adjusted to the metronome marking 120. A second disk carried by the central shaft above the first, gives opportunity for recording graphically the responses of the subject. The sound is produced when the current from one dry cell sent through the unaccented circuit, and that from three dry cells sent through the accented circuit, operates a telegraph sounder, and is completed in the contact rider, which acts as a common pole for both circuits. The subject taps the patterns as he receives them on a small wooden block with a wooden stylus. During this series of experiments the tapping of the subject was not recorded graphically, but Révész's procedure—the auditory comparison of response with stimulus by the experimenter—was followed.[1]

Method of giving the tests. Pitch, time, and intensity discrimination, consonance, tonal memory and auditory imagery were given by the group method on consecutive weeks to the students in the elementary harmony class at the School of Music. Later, the twenty people selected for this experiment were retested individually in the psychological laboratory, as a check on the first

[1] Since this time the apparatus has been improved and standardized. The test may now be given by means of the Columbia phonograph record No. 53005—D, A and B.

results. It is interesting to note that in all but two cases, where the subjects were nervous and high-strung, requiring more individual attention from the experimenter, the group results remained practically unchanged. Part of the reliability of the first tests undoubtedly was produced by the intelligent and interested coöperation of the students. The necessary conditions of quiet and lack of interruption were maintained throughout.

The motor tests were given in individual appointments of one half-hour each in the psychological laboratory. The time spent in these amounted to about three hours in all for each person.

Supplementary data. In addition to the above tests, information was secured regarding the musical environment, interests, and training of the selected students. For this purpose, the questionnaire compiled by Dr. Hazel Stanton, for use in the Eastman School of Music of Rochester, New York, was used.[1]

Questionnaire

General information

Name in full .... Date of birth....................
General education, kind .... Extent ....
Favorite studies ....
Interests, vocational ....
Avocational ....

Musical environment during youth

What musical instruments have you in your home?...... ....
Who in your family plays these instruments?............................
Who in the family sings?..
Do you play or sing together in your home?..............................
Does anyone outside your family come into your home to play and sing?......
What places outside your home do you hear music?........................
About how many musical programs do you attend a year?..................
What kind of musical programs do you hear?.............................

Musical education and training

How many years have you studied music in schools?........................
Number of half-hour lessons on the piano?..............................
On any other instrument?..
(name of instrument) (No. hours)
Number of half-hour private singing lessons?............................
Easy range of the voice in singing?......................................

[1] The writer wishes to express gratitude to Dr. Stanton for her permission to publish this questionnaire.

Number of years study in harmony.............. ear training..............
history of music.............. appreciation.............. sight singing
.... orchestration............. composition..............
public school methods?..

Musical activity

Do you play alone in public?............. Where?........................
On what instrument?................. How often?................
Do you play in an orchestra or band?......... What instrument?...........
Do you sing in public alone? .... Where?.......................
How often?..................
Can you carry a tune easily?.............
Do you sing in choir, chorus, or glee club?.......... How often?...........
Where?.................... What part do you sing?...............
Name the most difficult selection you can play ....
(name)
.... You can sing..................................
(composer) (name)
....
(composer)
Are you professionally engaged in music?............... If so, in what capacity? ....
Do you improvise?............. Compose?............. To what extent?
.... Play by ear?..............

Musical interests

What kind of musical entertainment do you prefer?.........................
What type of music appeals to you most?...................................
Who are your favorite composers?..
Have you ever experienced any emotional reaction to music?................
Specify as to the nature of this reaction................................
What type of music aroused it?...
Has his experience or any other occurred repeatedly?....................
State at least two reasons why you are studying music.......................
....

Musical memory and imagination

How easily do you memorize?...
What devices do you use in memorizing music?..............................
In the absence of musical stimulation can you hear in detail previously heard melodies?..
Do you ever hear melodies new to you?.....................................
If so, are you able to play or sing them?.................................

Performance Tests

The ratings of musical performance took place at the School of Music on five Saturday afternoons during the months of January and February. An attempt was made to have no more than four students play in one afternoon, but at one time there

were three performers, and on the last afternoon, five. The tests lasted about 40 min. on each afternoon. Each student's performance lasted about 7 min. A committee of four judges, seated behind a screen in a room adjoining that in which the student played, rated the performance according to a previously determined scale.

Instructions to the selected students. A week before the afternoon on which the student was to play, he was interviewed by the writer. Since an attitude of personal friendship had been built up during the foregoing series of tests, the interviews were usually very informal talks in which the interest and readiness of the student to coöperate were easily secured. The purpose of the tests was not stated in detail. The student simply understood that a study was being made of the relation of his records in the capacity tests and his ability to play. His playing was to be listened to and judged by a committee whose identity was unknown to him, seated in a room adjoining that in which he played. His identity was to be concealed from them by means of a screen placed between the two rooms. He was told to come to the Music School at a certain hour, and he would be taken to the room in which he was to play.

In choosing his music, the pieces with which he was familiar were discussed at length. The piece finally selected was, in the student's judgment, the one which best represented his technical development, which he most enjoyed playing, and with which he felt most familiar from long practice. He was allowed to use the notes at the time of performance, or to play from memory, as he chose. Emphasis was laid on the fact that he was to do the thing that would allow him to appear at his best. There was also an attempt made to secure music that would not reveal the identity of the performer to the judges.

He was cautioned to maintain secrecy about the test. He was one of a series of performers, and to insure about an equal amount of practice for each person before the test, it was necessary not to have knowledge of the tests conveyed to the teachers and students. He was not told who would play on the afternoon

he was to appear, and he did not find out until the day in question. While absolute secrecy could not be maintained for obvious reasons, there was a most commendable coöperation on the part of the students who entered into it as a game with good sporting spirit.

Conditions under which the performance was given. The conditions under which the performances were given were uniform throughout the series. The tests took place in the studio of the director of the Music School. This room together with a small room adjoining could be shut off from the business offices of the School, and privacy assured for the period of the tests. There was an outside door to the studio through which the performers could enter as they were called. The piano on which they played was a Steinway Grand which stood just beside the door to the adjoining room. This room was entered by going up three steps from the studio, so that a screen placed in front of the door was above the level of the eyes of both performer and judges. The judges were urged not to whisper or to make any kind of noise that might possibly give a clue to their identity, while the students were cautioned not to speak above a whisper to the writer who remained in the studio with them to turn pages and give necessary instructions.

The judges were seated in the inner room, rating blanks distributed, and the screen put in place before the first performer of the afternoon was called from an adjoining studio. Each performer played twice, both for the sake of giving him a chance to overcome any nervousness he might have during the first performance, and to allow the judges to verify their first impressions of the playing. Two plans of repeating the piece were tried. The first five players played in " double fatigue order " [1] to allow for the advantage gained by the first two performers while the judges were fresh and unfatigued. But it was found that the judges did not become annoyingly fatigued, and that only the middle performer of the series, who played twice in succession, gained in assurance and warmth in her second performance. In all the

[1] That is, in the order 1, 2, 3, 4, 5, 5, 4, 3, 2, 1.

subsequent performances, each performer played the piece the second time as soon as its first rendition was finished and with only a short pause between.

After the first afternoon, no announcement of the piece or of the performer was made to the judges in the inner room. The students played one after the other, and the rating blanks were gathered by one of the judges after each performance. Only one rating was made of the two performances of each student. The accompaniments for the four violin students were all played by the same person.

The judges. The four judges who carried through the whole series of tests, and whose ratings comprise the "expert judgments" discussed under Results, were four professional musicians who have attained distinction in their art: Philip Greeley Clapp, Frank Estes Kendrie, Walter Leon, and Stella Reading Myser.[1]

Method of rating performances. In attempting to measure proficiency in artistic musical performance the writer was handi-

[1] Dr. Clapp is a graduate of Harvard, and was for two years Sheldon Fellow of Harvard University; pupil in composition and piano of John P. Marshall; in composition of Walter R. Spalding, and composition and conducting of Max Schillings (Stuttgart). He was director of music at Dartmouth College for three years; band leader, 73rd Artillery, A.A.R., A.E.F.; for ten years special musical correspondent to the Boston *Evening Transcript*. His compositions which have been performed include two symphonies, symphonic poems, and a prelude.

Frank Estes Kendrie is a graduate of Bowdoin College and Harvard University (M.A.); pupil in violin of Charles Martin Loeffler, F. Willy Kraft, Henry Eichheim, and Carl Barleben. He was first violin, St. Louis Symphony Orchestra for one season; and for four years Professor of Violin at the University of Kansas. He is at present Professor of Stringed Instruments in the State University of Iowa.

Walter Leon is a graduate of the Stern Conservatory, Berlin; pupil in voice of Jean de Reszke, Oscar Seagle, Alfred Baehrens, Vincenzo Sabatini, David Bispham. He has had operatic experience in Milan, Italy, and with the Moody-Manners Company, England. He is at present Professor of Vocal Training in the State University of Iowa.

Stella Reading Myser is a graduate of the Institute of Musical Art, New York City, with a major interest in piano. She was accompanist for a year in the Klibanski Studios in New York, and teacher of piano for two years at the Scarborough School, Scarborough-on-the-Hudson. At the present time she is not engaged in professional work.

The writer wishes to express her gratitude to the judges for their sincere and untiring coöperation in the tests. Their attitude throughout was most helpful.

capped by lack of precedent in the field. At present, universal and standardized criteria for performance do not exist. A rating scale used by competently trained judges seemed the nearest approach that could be made at this time to an evaluation of performance.

There were five criteria of performance chosen arbitrarily by the writer after informal decision with a group of musicians—time, tone-quality, intensity, rhythm, and the artistic unity of the performance as a whole. In the case of performance on the violin, the element of pitch was added. Since it seemed better to establish a common standard of judgment for all four judges than to make a rating scale much as that devised by *Scott* (29); and, since the selected students ranging in development from the seventh grammar grade to seniors in college, made division in fifths of a standard group impossible, the most effective method of establishing a common standard of judgment seemed to be definition of each degree of excellence in the five criteria. The degrees were designated as superior, excellent, high average, low average, inferior, and poor.[1] The definitions for each were decided on by the committee of judges and the writer. For rating the first eight performers, a less complete scale was used, in which only three defined degrees of excellence—excellent, average, and inferior, were used to estimate tone-quality, time, and rhythm. But since the judges felt that a more satisfactory rating was obtained by using the more complete scale, these criteria were expanded to correspond to the other three. It would have been an advantage in securing more exact ratings if the degrees of excellence could have been defined in terms of percentile distribution. The judges were too unfamiliar with this concept to make its use feasible. It seemed wiser to use the musical terminology with which they were familiar than to introduce what would have been to them only psychological abstractions.

Performance rating blank. The following is the rating blank

[1] For any future use of such a rating scale it is suggested that "poor" and "very poor" be substituted for "inferior" and "poor." There is a possibility that the latter terminology influenced the judgments unduly, and retarded, rather than furthered the five distinctions the writer desired from the judges.

used in estimating the performances. The final judgment was recorded by a check-mark beside the desired estimate.

Performance Rating Blank

Date ....
Performer........................ Music played........................

Pitch

Unconscious of it as a disturbing factor....................	Superior
Slightly conscious of it occasionally....................	Excellent
Questionable pitch occasionally....................	High average
Questionable pitch frequently....................	Low average
Bad deviation from pitch occasionally....................	Inferior
Bad deviation from pitch constantly....................	Poor

Time

Rubato balanced, tempo steady, accents and deviation from regular tempo noticeably artistic....................	Superior
Rubato balanced, tempo steady, accents and deviations satisfactory	Excellent
Rubato erratic, but general deviations satisfactory, tempo steady	High average
Rubato and general deviations erratic, tempo fairly steady..	Low average
Rubato and general deviations erratic, tempo fairly steady..	Inferior
No deviations, tempo erratic....................	Poor

Tone-quality

Good tone, varied ("singing," delicate or full) to suit the varying moods of the piece....................	Superior
Good tone, full, smooth, sweet, but not much variation.....	Excellent
Definitely avoids being disagreeable....................	High average
Not harsh, but uninteresting....................	Low average
Poor tone, harsh, tinny, thin....................	Inferior
Poor tone that becomes worse in places of technical difficulty	Poor

Intensity

Climaxes, fine contrast, delicate shading....................	Superior
Climaxes, contrast, shading, just less than satisfactory.....	Excellent
Climax, some contrast, little shading....................	High average
Contrast, no climax or shading....................	Low average
Infrequent, illogical contrast	Inferior
No contrast	Poor

Rhythm

Rhythm maintained through accelerandoes, ritards, and rubatos	Superior
Rhythm maintained only in places not presenting difficulties of interpretation or technique....................	High average
	Low average
Little or no rhythm in the performance....................	Inferior
	Poor

Analysis of Factors Involved

Variable factors from the standpoint of the judges. In considering the constant errors involved in rating schemes in general, the most outstanding is what Thorndike designates the "halo" error. This is a judgment in which rating of some special trait is colored by a general estimate of the person as a whole; that is, a halo of general merit is extended to influence the rating for special ability (34). Intercorrelations between the special traits therefore become too high and too even in their spread. The correlations themselves are the result of (1) the real facts; (2) the constant error of the halo; (3) the reverse error of attenuation, due to chance inaccuracies in the ratings.

In the present study, the five criteria of performance rated by the judges show a tendency to high intercorrelation. In other words, the ratings have the appearance of the "halo" error. Doubtless the error is characteristic of these judges as it is of all who estimate and rate. But it is difficult to determine in the situation just how serious the error is, and what weight should be attached to it.

The factors composing such a synthetic whole as musical performance may be closely related. High correlation between them may be, instead of a "halo" error, only an indication of the real facts. The criterion of time, in performance, for example, correlates with tone-quality .73, p.e., .07; intensity, .85, p.e., .04; rhythm, .82, p.e., .04; and artistic unity, .92, p.e., .009. But when the objective results of the capacity tests for this same selected group of students are intercorrelated, the perception of time correlates with pitch .81, p.e., .04; intensity .53, p.e., .10; consonance, .51, p.e., .10; memory .39, p.e., .13; while pitch correlates with intensity .63, p.e., .09; consonance .49, p.e., .11; and memory .67, p.e., .08.[1] Since even standardized musical capacity tests correlate "too highly" and are "too even in their spread" to be wholly independent of each other, it is to be expected that the criteria of performance should correlate highly. Musical performance is even more of a unit than are musical capacity tests.

[1] These correlation coefficients are obtained by the Spearman ρ [rho].

There are at least two interpretations, then, of these data—the " halo " error, and the genuine interrelationship of the factors comprising musical talent. The fair viewpoint, in the writer's opinion, is to admit a tendency toward this constant error on the part of the judges, but to recognize the close relationship of the facts with which the ratings are concerned.

Familiarity with the music played was a handicap to unprejudiced judgment. In each estimate, one or two of the judges had either themselves played the piece performed by the student, or had heard it played many times by artists, so that a definite standard of performance had been built up in their minds. On the other hand, the genuine artistic performance of the student was the thing to be estimated, and the high standards of the judges made the resulting estimates more significant. On the other hand, there was no one judge familiar with every piece played, and no two judges whose familiarity with the music coincided at every point. The average of the four standards for each estimate remained practically constant. There was but one judge who knew none of the students, and could consequently remain uninfluenced in her ratings by any previous knowledge of the student's work. In spite of caution, the other three judges were prone to guess at the identity of the performer. And when the music played gave a definite clue, it is doubtful if the final estimate was wholly unprejudiced by their knowledge of the training and usual standard of performance of the student. But here again, the error was not constant with any one of the three judges, since two control performances introduced into the series acted as a check on their identification of the selected group. The errors thus made in the ratings tended to balance among the three judges, and the fourth estimate kept the average standard of judgment again practically constant.

Variable elements from the standpoint of the performer. The musical background of the performer, and the amount and quality of his musical training, loom up so importantly in any discussion of performance that his real musical capacity seems buried by those external factors. Not only does the training of these 20

students range from 10 half-hour lessons to 800 half-hour lessons, but the amount of music actually taught in those half-hours, and the amount and quality of practice in preparation for the lessons varies as widely.

An ideal selection of students for this study would have included only those with the same number of hours of training, and with similar musical environment. Training would then have been a constant factor in the interpretation of the data, with musical performance and capacity as variables. A true picture would thus be presented of the relation between the two latter factors. However, in a music school of 200 students it is impossible to select from a group studying any one instrument, or even any two, enough students with similar training to make an investigation such as this of value. Rather than work with such a small group, it seemed to the writer better to accept the difficulties introduced by unequal training, and to take account of that fact in drawing conclusions.

One outstanding difficulty is that the pieces played do not represent independent musical thought on the part of the student. They can at best be but the product of the personality of the student and a carefully drilled interpretation on the part of some teacher. It was at first thought advisable to present to each student, or to several students with approximately the same amount of training, a new piece of music, with which he was unfamiliar, and to base judgment of his performance on his interpretation of that music. But even if rigid conditions or supervised practice could be secured to insure that no student received aid in preparing his piece, and that the number of hours of practice for each were exactly the same, the interpretation would in the end reflect the qualities of performance which had been most carefully emphasized in the student's hours of training. In the long run, the difficulties of either method would be about the same, since in the method chosen, the music played had been practiced for a period of months, and the interpretation of it had become practically a part of the student's own manner of thinking.

This unevenness of training necessarily resulted in an uneven-

ness in the difficulty of the music played. The judges attached no greater merit to the performance of a difficult piece than to that of an easier one. It was understood that each piece represented the highest level of achievement of the student playing it, and the performance was rated for the artistic rendition of that particular piece, without reference to any other.

Another important difficulty in rating lies in the fact that the performer is not a finished musical product. His training has not been completed; he is still in the midst of it. He may be passing through the awkward phase attendant on every stage of eventual progress, or he may have mastered one element of performance without having brought the others up to the same level of proficiency.

Stage-fright and his previous experience in playing for an audience are two factors which may be a serious handicap in allowing a judge to reach a true estimate of a student's ability to play. Although the fact that his audience is not in the same room eliminates part of the strain, the student's nervous tone under such condition is not that which he practices and, except in rare cases, is a hindrance rather than a help to good performance. That part of this is overcome as the student adjusts to his unfamiliar surroundings as shown by the fact that usually, the second rendition of the piece played was a noticeable improvement over the first. Yet the point remains that ordinarily the less training and experience the student has, the greater his handicap of nervousness. This coupled with his lack of skill, makes an unequal weighting of his disadvantages as against those of the more adequately trained student.

Talent Charts, Performance Ratings and Musical Training

In the following pages are presented the results of the measurements of musical capacity, the judges' estimates of musical performance, and the musical training and background of each of the twenty selected students. A reference letter has been assigned to each.

The results of all of the tests except serial action, rhythm,

reaction-time, and intensity control are scored in terms of percentile rank, based on large, unselected groups. The other four tests are scored in terms of excellent, average, and inferior, where average represents the median score made in the test by this selected group, excellent a score higher than median, and inferior a score lower than median. The intelligence tests are the Thorndike Intelligence Examination for High School Graduates, the results being in terms of percentile rank based on over 1,000 Iowa University freshmen.

The performance ratings are the actual frequency of the marks given by the judges. Performers A to F had two estimates each, of their playing.

The information regarding the training of each student was compiled from the questionnaire given in the chapter on Procedure.

Fig. 1. Performer A

	POOR 1-10	INF. 11-30	L. AV. 31-50	H.AV. 51-70	EX. 71-90	SUP. 91-100	
PITCH						✓	CAPACITY
INTENSITY						✓	
TIME						✓	
CONSONANCE						✓	
MEMORY						✓	
IMAGERY						✓	
INT. CONT.					✓		
SER. ACT.				✓			
RHYTHM					✓		
MOTILITY		✓					
PURSUIT	✓						
SIM. REACT.				✓			
INTEL.							
TIME				4	4		PERFORMANCE
TONE-QUAL.				4	4		
INTENSITY				1	4	3	
RHYTHM					6	2	
ART. UNITY				3	4	1	

Performer A

Music played: Eintritt (*Schumann*)

Conditions of performance: This performer was a control introduced as a check on the ability of the judges to identify the players. It was not thought necessary at first to include her record with the rest, since in a strict sense she was not a student in the music school. But owing to the illness of one of the 20 selected students at the time set for her test, the findings on performer *A* are reported with the others. Performers *A* and

J were the same person. When on the day of *J's* performance one of the selected group was ill, *A* played Schumann's Romance, *Op.* 28, No. 2, as a substitute, consciously playing as badly as possible. Since the ratings, however exact, were made on spurious facts, the results have been omitted from discussion.

Musical history: Mother and father sing; sister plays. Heard from 5 to 8 concerts a year during youth, and a year of opera and symphony during graduate work in New York; 12 years public school music; 800 half-hour lessons on piano; 72 half-hour lessons on violin. Harmony, appreciation of music, counterpoint and composition were college majors, followed by a year of study in New York in which composition was the major interest.

A has appeared in public recitals ever since childhood, and has given concerts alone. She has had choir, chorus, and glee club experience, as well as conducting all three. MSS. compositions include songs, piano pieces, and orchestral works. *A* improvises and plays by ear.

Orchestral music appeals to *A* more than any other, and modern music produces more emotional reaction than the Mozart-Beethoven type. *A's* reaction to music has always been intense, at times almost overwhelming. She has made music a semi-vocational interest.

Fig. 2. Performer B

		POOR 1-10	INF 11-30	L. AV. 31-50	H.AV. 51-70	EX. 71-90	SUP. 91-100
CAPACITY	PITCH		✓				
	INTENSITY						✓
	TIME						✓
	CONSONANCE						✓
	MEMORY	✓					
	IMAGERY		✓				
	INT. CONT.						
	SER. ACT.						
	RHYTHM						
	MOTILITY						
	PURSUIT						
	SIM. REACT.						
	INTEL.						
PERFORMANCE	TIME		8				
	TONE-QUAL.		5	3			
	INTENSITY	6	1	1			
	RHYTHM		5	3			
	ART. UNITY	8					

Performer B

Music played: Valse Serieuse (composer missing)

Conditions of performance: Performers *B* and *D* were sisters, having practically the same musical background, but *D* has had more training. *B* has had no experience in playing for listeners and was consequently more than ordinarily ill at ease. Her performance was halting and stumbling. She left school after the first semester because of failure in her class-work, which consisted largely of music courses, and so was unable to complete the motor tests.

Musical history: No one in *B's* family sings, but a sister plays a little. *B* hears about 6 concerts a year at the Chautauqua, church, and lyceum courses.

B has had no public school music, and only 10 half-hour piano lessons. She has had 6 violin lessons, and one semester of elementary harmony.

B gives no record of any kind of musical activity, except her own piano practice.

Her musical preferences are not very definite, although she likes orchestra, and quartettes. The type of music that appeals to her changes with her mood.

Fig. 3. Performer C

		POOR 1-10	INF. 11-30	L. AV. 31-50	H.AV. 51-70	EX. 71-90	SUP. 91-100
CAPACITY	PITCH					✓	
	INTENSITY				✓		
	TIME				✓		
	CONSONANCE						✓
	MEMORY					✓	
	IMAGERY					✓	
	INT. CONT.		✓				
	SER. ACT.				✓		
	RHYTHM		✓				
	MOTILITY			✓			
	PURSUIT	✓					
	SIM. REACT.		✓				
	INTEL.				✓		
PERFORMANCE	TIME		3		5		
	TONE-QUAL.		3		5		
	INTENSITY	2	3		3		
	RHYTHM				8		
	ART. UNITY	1	3		4		

Performer C

Music played: Spring Song (*Mendelssohn*)

Conditions of performance: *C* is probably capable of giving a better performance than she did. The action of the piano was rather heavy, and *C* was unable to adjust to it. Her intensity and tone-quality both varied illogically because of inadequate technique.

Musical history: Father, mother, and sisters sing, but there is not much group singing in the home. *C* hears one or two lyceum course programs a year.

C has had no public school music; 50 half-hour lessons on the piano; 12 private singing lessons; one semester elementary harmony.

C has played in public piano recitals two or three times a year, and has sung in a chorus.

Glee club, band, and "slow, dreamy music" are what *C* prefers, and her favorite composer is Mendelssohn. She has no specific emotional reaction, but a pleasant, diffused feeling of enjoyment when listening to it.

Fig. 4. Performer D

	POOR 1-10	INF. 11-30	L. AV. 31-50	H. AV. 51-70	EX. 71-90	SUP. 91-100	
PITCH		✓					CAPACITY
INTENSITY			✓				
TIME					✓		
CONSONANCE				✓			
MEMORY	✓						
IMAGERY							
INT. CONT.			✓				
SER. ACT.							
RHYTHM							
MOTILITY							
PURSUIT							
SIM. REACT.							
INTEL.							
TIME		2	6				PERFORMANCE
TONE-QUAL.		3	5				
INTENSITY		3	5				
RHYTHM			8				
ART. UNITY		1	7				

Performer D

Music played: Polish Mazurka

Conditions of performance: *D* was quite unruffled during the test and probably played as well as she would under ordinary circumstances. Because of failure in class-work, consisting largely of music courses, *D* left the University after the first semester, and was unable to complete the series of tests.

Musical history: There is practically no music in *D's* home, although the mother and father have sung a little at one time. *D* hears two or three programs a year at the Chautauqua.

D has had one year of public school music; 48 half-hour lessons on the piano; 72 half-hour lessons on the violin; one semester of elementary harmony.

D plays in an orchestra, and in a piano recital about once a year. She does not sing at all.

Slow, soft orchestral effects are the kind *D* likes to enjoy in music. Beethoven and Schumann are her favorite composers.

Fig. 5. Performer E

		POOR 1-10	INF. 11-30	L. AV. 31-50	H. AV. 51-70	EX. 71-90	SUP. 91-100
CAPACITY	PITCH						✓
	INTENSITY						✓
	TIME						✓
	CONSONANCE						✓
	MEMORY						✓
	IMAGERY				✓		
	INT. CONT.		✓				
	SER. ACT.					✓	
	RHYTHM					✓	
	MOTILITY			✓			
	PURSUIT						✓
	SIM. REACT.				✓		
	INTEL.						
PERFORMANCE	TIME				6	2	
	TONE-QUAL.				4	4	
	INTENSITY				6	2	
	RHYTHM			1	2	5	
	ART. UNITY			2	6		

Performer E

Music played: Mazurka (*Mylnarski*)

Musical history: Two sisters play piano and violin, and all the family sing. Friends come into the home to play and sing. *E* hears nine or ten artist-concerts a year.

E has had public school music for twelve years; 500 half-hour lessons on the piano; 145 lessons on violin; one year harmony; one semester music appreciation.

E plays at church, at entertainments of various kinds and in recitals. She plays in the university orchestra. While she has had no singing experience, she carries a tune easily. *E* also improvises.

Orchestra, and slow and expressive music are *E's* preferences. Beethoven, Grieg, and Mozart are her favorite composers. She reacts to music with "crying and happiness."

Fig. 6. Performer F

		POOR 1-10	INF. 11-30	L. AV. 31-50	H. AV. 51-70	EX. 71-90	SUP. 91-100
CAPACITY	PITCH					✓	
	INTENSITY						✓
	TIME					✓	
	CONSONANCE						✓
	MEMORY						✓
	IMAGERY		✓				
	INT. CONT.					✓	
	SER. ACT.		✓				
	RHYTHM				✓		
	MOTILITY		✓				
	PURSUIT	✓					
	SIM. REACT.		✓				
	INTEL.						
PERFORMANCE	TIME				1	3	
	TONE-QUAL.				3	1	
	INTENSITY					4	
	RHYTHM					4	
	ART. UNITY					3	

Performer F

Music played: Barcarolle in A Minor (*Rubinstein*)

Musical history: The father sings, and when the children were young and the mother living, the whole family used to sing together. *F* hears five or six good musical programs a year.

F has had 360 half-hour lessons on the piano; two years of harmony; two of music appreciation; and one-half year of public school methods.

F plays perhaps ten times a year in piano recitals. She does not sing, and has had no chorus or choir experience.

Piano music appeals most to *F*. Her favorite composers are Chopin, Liszt and Bach. Her reaction to music is one of "hurt, thrill, and sense of power."

Fig. 7. Performer G

		POOR 1-10	INF. 11-30	L. AV. 31-50	H. AV. 51-70	EX. 71-90	SUP. 91-100
CAPACITY	PITCH					✓	
	INTENSITY						✓
	TIME						✓
	CONSONANCE						✓
	MEMORY						✓
	IMAGERY					✓	
	INT. CONT.		✓				
	SER. ACT.			✓			
	RHYTHM			✓			
	MOTILITY					✓	
	PURSUIT				✓		
	SIM. REACT.					✓	
	INTEL.						
PERFORMANCE	TIME				2	2	
	TONE-QUAL.				3	1	
	INTENSITY				1	3	
	RHYTHM					4	
	ART. UNITY				2	2	

Performer G

Music played: Witches' Dance (*MacDowell*)

Conditions of performance: Since there was a disturbing number of wrong notes in *G's* playing of the "Witches' Dance," the judges were prone to penalize her by lower ratings on artistic unity than would otherwise have been the case.

Musical history: *G's* father, sister, and herself play piano, violin, and flute together, and the father sings. Friends also come into the home to play. *G* hears four or five good concerts a year.

G has had 344 half-hours on the piano; 4 years of harmony; 4 years of music appreciation; and 1 year of composition.

G plays at clubs, schools, and entertainments two or three times a month. She does not sing, although she carries a tune fairly well. She is professionally engaged in teaching piano.

Orchestral music appeals to *G* most, and Tschaikowsky, Grieg, and Beethoven are her favorite composers. Her emotional reaction to music she describes as "chills," adding that this occurs repeatedly.

Fig. 8. Performer H

	POOR 1-10	INF. 11-30	L. AV. 31-50	H. AV. 51-70	EX. 71-90	SUP. 91-100	
PITCH					✓		CAPACITY
INTENSITY					✓		
TIME					✓		
CONSONANCE		✓					
MEMORY						✓	
IMAGERY					✓		
INT. CONT.					✓		
SER. ACT.		✓					
RHYTHM			✓				
MOTILITY		✓					
PURSUIT	✓						
SIM. REACT.		✓					
INTEL.					✓		
TIME		1	3				PERFORMANCE
TONE-QUAL.			3		1		
INTENSITY		1			3		
RHYTHM				4			
ART. UNITY		1	2	1			

Performer H

Music played: To Spring (*Grieg*)

Conditions of performance: *H's* playing was characterized by a peculiar heavy-handedness, which resulted in a rather uninteresting tone-quality throughout. Her conception of the piece as a whole was at fault, rather than any one specific element.

Musical history: Mother sings a little; no family singing in home, and no one from outside comes in to play or sing. *H* hears music at church, and at university concerts. She hears about five programs a year.

H has had music in the public schools for 12 years; 288 half-hours of piano instruction; 22 half-hours of singing lessons; 1 semester of elementary harmony.

H sings in university chorus and glee club, and has played in piano recitals. *H* plays by ear a little, and carries a tune easily.

H likes musical comedy or opera better than any other kind of music and is especially interested in singing. MacDowell and Grieg are her favorite composers. Her reaction when listening to music is "tenseness, relaxation," and this is aroused particularly by martial and dreamy music.

Fig. 9. Performer I

	POOR 1-10	INF. 11-30	L. AV. 31-50	H.AV. 51-70	EX. 71-90	SUP. 91-100	
PITCH				✓			CAPACITY
INTENSITY					✓		
TIME						✓	
CONSONANCE			✓				
MEMORY					✓		
IMAGERY				✓			
INT. CONT.		✓					
SER. ACT.					✓		
RHYTHM					✓		
MOTILITY				✓			
PURSUIT		✓					
SIM. REACT			✓				
INTEL.							
TIME		1	3				PERFORMANCE
TONE-QUAL.			3		1		
INTENSITY		1	1	2			
RHYTHM				2	2		
ART. UNITY			4				

Performer I

Music played: Prelude from Carnival Mignonne (*Schutt*)

Conditions of performance: *I* was so hampered by nervousness that her playing does not represent her real ability as shown in recitals, group meetings of the piano students, and her lessons. Her second performance was poorer than the first. She is the one case in the twenty in which otherwise marked ability was decidedly inhibited by the presence of the judges. Although *B* was nervous for the same reason, she had never given any evidence under normal circumstances of being able to give an artistic performance.

Musical history: Although *I's* brothers and sister play violin and piano, and her sister and father sing, there is not much group music in her home. Friends come in to play and sing only rarely. *I* hears about twelve good concerts a year, during the university sessions, and the Chautauqua season.

I has had 309 half-hour lessons on the piano; 1½ years of harmony; 1½ years of music appreciation.

I's musical activity is confined to playing in piano recitals once or twice a year. She has had a little chorus experience, and carries a tune with a fair degree of ease.

I prefers concerts of instrumental music. Chopin and Mendelssohn are her favorite composers. Music rouses her enthusiasm, makes her either gay or thoughtful.

Performer J

See Performer A

Fig. 10. Performer K

		POOR 1-10	INF. 11-30	L. AV. 31-50	H. AV. 51-70	EX. 71-90	SUP. 91-100
CAPACITY	PITCH					✓	
	INTENSITY						✓
	TIME					✓	
	CONSONANCE					✓	
	MEMORY					✓	
	IMAGERY				✓		
	INT. CONT.		✓				
	SER. ACT.		✓				
	RHYTHM					✓	
	MOTILITY					✓	
	PURSUIT	✓					
	SIM. REACT.					✓	
	INTEL.						
PERFORMANCE	TIME				4		
	TONE-QUAL.		1		1	1	1
	INTENSITY		1		1	2	
	RHYTHM			1	2	1	
	ART. UNITY		1	1	1	1	

Performer K

Music played: Nocturne, Op. 48, No. 1 (*Chopin*)

Conditions of performance: K's control of dynamics was rather poor, and her technique inadequate to the demands put on it by the Nocturne she played. While the octave passages in the middle section lent a spurious brilliance to the whole, *K* would have appeared to better advantage with less pretentious music.

Musical history: While *K* hears no music in her home except her own playing, she hears twelve or more artist concerts a year.

K has had four years of public school music; 184 half-hours of piano lessons; 1½ years of harmony; history of music; and 1½ years of music appreciation.

K plays very often in piano recitals, and for entertainments of various kinds. She does not sing, nor improvise, but plays by ear a little.

Symphony concerts, sometimes pianists, are what *K* enjoys most. In her reaction to music, she "experiences everything. It lifts me completely out of myself."

Fig. 11. Performer L

	POOR 1-10	INF. 11-30	L. AV. 31-50	H. AV. 51-70	EX. 71-90	SUP. 91-100	
PITCH						✓	CAPACITY
INTENSITY						✓	
TIME						✓	
CONSONANCE						✓	
MEMORY					✓		
IMAGERY							
INT. CONT.		✓					
SER. ACT.		✓					
RHYTHM		✓					
MOTILITY	✓						
PURSUIT		✓					
SIM. REACT.		✓					
INTEL.					✓		
TIME		2	2				PERFORMANCE
TONE-QUAL.		1	3				
INTENSITY	3		1				
RHYTHM			1		3		
ART. UNITY		2	2				

Performer L

Music played: Sur le lac (*Borowski*)

Conditions of performance: *L* is a child in the seventh grade, whose high sensory capacities attracted the notice of his teachers, who sought means of giving him the musical education his talent seemed to warrant. He has had about 36 lessons on the violin. No explanation was made to the judges before his performance as to his identity, and they rated him by the same standards applied to the others.

Musical history: There is a piano, a violin, and a phonograph in *L's* home, and since his mother plays piano very little, and he himself has not had his violin a year, the phonograph contributes most to his musical education. Friends come in to play and sing occasionally, but he prefers the violin records they have to the music the others make. He hears about 5 good concerts a year.

L has had music in school the seven years he has attended. He has had 36 violin lessons, and usually practices about 5 hours for each lesson.

L has a good singing voice which he enjoys using at day and Sunday-school. His teacher "always praises his voice." *L* does not play alone yet, but plays in a Sunday-school and school orchestra. He sometimes plays the melodies he hears on the phonograph, standing with his violin before the instrument, and picking out his notes as the piece is played.

An orchestra, a band, a violin—these appeal about equally to *L*. He is too undeveloped yet to have very definite emotional reactions to music, but he says that as the piece is played he "thinks about the man who wrote it, and wonders how he got to be a musician."

Fig. 12. Performer M

		POOR 1-10	INF. 11-30	L. AV. 31-50	H.AV. 51-70	EX. 71-90	SUP. 91-100
CAPACITY	PITCH					✓	
	INTENSITY						✓
	TIME						✓
	CONSONANCE				✓		
	MEMORY				✓		
	IMAGERY						✓
	INT CONT.					✓	
	SER. ACT.				✓		
	RHYTHM					✓	
	MOTILITY						✓
	PURSUIT						✓
	SIM. REACT					✓	
	INTEL						✓
PERFORMANCE	TIME			1		1	2
	TONE-QUAL			1		2	1
	INTENSITY			1		1	2
	RHYTHM		1			1	2
	ART. UNITY			1		1	2

Performer M

Music played: Legende (*Wieniawski*)

Conditions of performance: The writer hesitates to include the ranks of *M's* sensory capacities in the record, for there is not sufficient evidence that they are reliable. If true measure of them could be secured, they would probably lie in the superior group. *M* is younger than most college freshmen, and while possessing singular poise and an unusually winsome personality, gives evidence of the nervous instability of adolescence. Most of the capacity tests were repeated 4 times. His adaptation to test conditions improved each time, but he fatigued so quickly and found concentration so difficult after the first 5 minutes that in spite of various means of relaxation introduced into the experiments, there was never a time when the writer was sure his true physiological limit had been found by the test. His motor capacities are distinctly superior. His record in pursuit was the highest of the twenty. He approached all his motor tests with sureness and ease.

Musical history: In *M's* home, the mother, sisters and brother play piano, violin, and 'cello, while the mother and brother also sing. *M* plays trios and solos with them. Friends, violinists and pianists, come into the home to play and sing. *M* hears about twenty-five orchestral, vocal, piano and violin concerts a year.

M has had music in the public schools eight years; 476 half-hour lessons on the violin; and one semester of elementary harmony.

M has played on Chautauqua circuit, and in a hotel orchestra. He plays in the university orchestra, and has played in recitals and on church programs to the extent of once or twice a week. He carries a tune easily.

M prefers to listen to orchestras, and to string instruments. The type of music he enjoys changes as his mood changes. His emotional reaction is very intense, "inexplicable." This reaction occurs repeatedly. Chopin, Beethoven, Bach, Wieniawski, Liszt are his favorite composers.

Fig. 13. Performer N

		POOR 1-10	INF. 11-30	L. AV. 31-50	H. AV. 51-70	EX. 71-90	SUP. 91-100
CAPACITY	PITCH					✓	
	INTENSITY						✓
	TIME						✓
	CONSONANCE					✓	
	MEMORY						✓
	IMAGERY						✓
	INT. CONT.					✓	
	SER. ACT.					✓	
	RHYTHM					✓	
	MOTILITY			✓			
	PURSUIT	✓					
	SIM. REACT				✓		
	INTEL.						
PERFORMANCE	TIME		1	1	1	1	
	TONE-QUAL.		1	1	2		
	INTENSITY		1	1	2		
	RHYTHM			2	2		
	ART. UNITY		2	1	1		

Performer N

Music played: In Autumn (*MacDowell*)

Conditions of performance: *N* has had the most interesting musical history of the twenty selected students, and his music represents more than that of anyone else his own ability rather than the training he has received. He has practically taught himself to play. When the writer asked about the music he could play for a performance test, his first suggestion was excerpts from "Die Rheingold." On the grounds that it would be better to confine the music to more pianistic vernacular, this suggestion was refused. Since he had brought no piano music to college with him, he borrowed a copy of MacDowell's "Woodland Sketches," and learned by himself (without the writer's knowledge), "In Autumn." His performance of it was not brilliant, but it was decidedly musical and, in the writer's opinion, deserved a higher rating than that accorded by the judges.

Musical history: There is no one in *N's* home who sings, but his mother plays piano, and has been his best teacher. She has played to him a great deal. The only places outside his home that he hears music are at church, and at the local Chautauqua. He hears about 10 programs a year.

He has had music in the public school for 7 years; 150 half-hour lessons on the piano. He has studied harmony 1 year, and composition for 5 years. His actual training does not bulk large in number of hours, but his dominant interest from childhood has been musical. With the aid of a book on harmony, he gave himself his first composition lessons, and wrote for orchestra without ever having heard one. His conception of the tone-quality of the different instruments was gained through his familiarity with the one pipe organ in his village.

He has played piano once a week,at least, at church and school and entertainments. While he has had no singing experience, he carries a tune easily. He has composed music, and improvises and plays by ear.

N states that he is studying music to write opera and conduct orchestra. Opera and symphony appeal to him most, and he prefers music of the Wagnerian type, although he is interested in the music of Verdi, Bizet, Gounod, also. His reaction to music is ecstasy.

Fig. 14. Performer O

		POOR 1-10	INF. 11-30	L. AV. 31-50	H. AV. 51-70	EX. 71-90	SUP. 91-100
CAPACITY	PITCH				✓		
	INTENSITY			✓			
	TIME	✓					
	CONSONANCE	✓					
	MEMORY		✓				
	IMAGERY				✓		
	INT. CONT.						
	SER. ACT.					✓	
	RHYTHM			✓			
	MOTILITY		✓				
	PURSUIT		✓				
	SIM. REACT.			✓			
	INTEL.						✓
PERFORMANCE	TIME	1	1	1		1	
	TONE-QUAL.		3			1	
	INTENSITY		2		2		
	RHYTHM			3	1		
	ART. UNITY	1	2	1			

Performer O

Music played: Impromptu, Op. 142 (*Schubert*)

Conditions of performance: O has no sensory or motor capacities that lie above high average. Her teachers are pleased at the progress she is making in her music, and consider her one of the good students of the freshman class. Her intelligence is superior, and no doubt she responds quickly and effectively to instruction. But in conditions of actual performance the real weakness of her musical equipment is brought to light. As in the case of *C*, being unaccustomed to the heavy action of the piano made it hard for her to accommodate, but even that could hardly have accounted for her utterly uninteresting rendition of the Schubert "Impromptu."

Musical history: O's brothers and sisters play the piano and violin, and her mother and sisters sing. There is informal group singing in the home. Sometimes others come in to play or sing. *O* hears about eight concerts a year, of singers, pianists, and Chautauqua groups of performers.

She has had music in the public schools for 8 years; 150 half-hour lessons on the piano; and 1 semester of elementary harmony.

O has played alone in public recitals and at church. She picks out tunes on piano with right hand alone, but does not improvise.

O has no very specific preferences as to types of music. Mozart is her favorite composer. She experiences elation when listening to music, and is studying it because of a desire to learn the technique of the art.

Fig. 15. Performer P

		POOR 1-10	INF. 11-30	L. AV. 31-50	H. AV. 51-70	EX. 71-90	SUP. 91-100
CAPACITY	PITCH			✓			
	INTENSITY				✓		
	TIME			✓			
	CONSONANCE						✓
	MEMORY				✓		
	IMAGERY				✓		
	INT. CONT.		✓				
	SER. ACT.		✓				
	RHYTHM			✓			
	MOTILITY					✓	
	PURSUIT			✓			
	SIM. REACT.			✓			
	INTEL.						✓
PERFORMANCE	TIME			1	1	1	1
	TONE-QUAL.				1	1	2
	INTENSITY				1	3	
	RHYTHM					3	1
	ART. UNITY				2	1	1

Performer P

Music played: Ase's Tod, *Op.* 46, No. 2 (*Grieg*)

Conditions of performance: Performer *P* is a good example of a student with average musical equipment, but with a superior intelligence that uses to the best advantage the talent she possesses. Only one of her sensory ratings is above high average. Motility is in the excellent group, a significant fact for good pianistic work. "Ase's Tod" was perhaps not as difficult technically as some of the music she plays, so that with a good conception of it, and perfect ease in its rendition, she was able to produce a significant performance that would argue higher equipment than she seems to possess. The capacity tests were given to her once in the group tests, and twice by individual appointment, at intervals of two months. Her ranks remained exactly the same each time.

Musical history: Two sisters and one brother play piano; father, mother, and brother sing. They play and sing together in the home. Two professional singers visit the home, and *P* accompanies their singing. She hears 6 artist-concerts a year.

P has had 12 years of public school music; 70 half-hour lessons on piano; a few singing lessons.

P plays piano at church and community programs about 12 times a year; has had choir, chorus, and glee club experience; carries a tune easily; and has taught music to primary children.

P likes best to listen to symphony orchestra music. Her favorite composers are MacDowell, Bach, Mozart, Massenet. In listening to music, she is "lifted out of herself."

Fig. 16. Performer Q

		POOR 1-10	INF. 11-30	L. AV. 31-50	H. AV. 51-70	EX. 71-90	SUP. 91-100
CAPACITY	PITCH					✓	
	INTENSITY				✓		
	TIME						✓
	CONSONANCE				✓		
	MEMORY					✓	
	IMAGERY				✓		
	INT. CONT.						
	SER. ACT.			✓			
	RHYTHM		✓				
	MOTILITY				✓		
	PURSUIT						✓
	SIM.-REACT.					✓	
	INTEL.		✓				
PERFORMANCE	TIME		1	1	1	1	
	TONE-QUAL.			3			1
	INTENSITY		1		2		
	RHYTHM		1	1	1	1	
	ART. UNITY		1	3			

Performer Q

Music played: Cavatina (*Raff*)

Musical history: Since in *Q's* home there is a violin, piano, clarinet, saxophone, drums, phonograph, and banjo, it is not surprising that ensemble playing has been an important part of his family life, as well as his musical life. In lecture courses and Chautauquas he hears 6 or 8 concerts a year.

He has had music in the public schools for about 8 years; 350 half-hour lessons on the violin; and 1 semester elementary harmony.

Q has played at recitals, and has had orchestra experience. He does not sing, but can carry a tune fairly well.

Q has rather catholic tastes in music, liking "concerts, musical comedy, also jazz music." He has no preference, "likes all kinds." Music, after he has been working, "removes tiredness, adds life."

Fig. 17. Performer R

		POOR 1-10	INF. 11-30	L. AV. 31-50	H. AV. 51-70	EX. 71-90	SUP. 91-100
CAPACITY	PITCH						✓
	INTENSITY						✓
	TIME						✓
	CONSONANCE						✓
	MEMORY						✓
	IMAGERY						✓
	INT. CONT.			✓			
	SER. ACT.					✓	
	RHYTHM					✓	
	MOTILITY			✓			
	PURSUIT				✓		
	SIM. REACT.		✓				
	INTEL.						
PERFORMANCE	TIME		1		1	2	
	TONE-QUAL.				2	1	1
	INTENSITY				3	1	
	RHYTHM			2	1	1	
	ART. UNITY			2	1	1	

Performer R

Music played: First Movement Sonata, *Op.* 110, No. 1 (*Beethoven*)

Conditions of performance: *R* is undoubtedly endowed with exceptional sensory talent, but her general nervous equipment is so unstable that she is liable to give a very erratic musical performance. Her variations in time and intensity were logical, and her tone-quality unusually good, but her rubatos were unbalanced and the general effect of her performance jerky and temperamental.

Musical history: *R's* mother plays the piano, and *R* plays and sings. *R* is employed as the secretary of a musician, and hears good music every day. The formal concerts she hears during the year number about 5 or 6.

R has had 420 half-hour lessons on the piano; 144 half-hour singing lessons; 2 years of harmony; one-half year of ear-training; 2 years history of music; 2 years music appreciation; one-half year sight singing; 1 year composition; 1 semester public school methods.

R appears in piano recitals about once a year, but sings in public at least once a week. She is professionally employed in a church quartette, and has broad chorus, choir, and glee club training.

Opera is *R's* chief delight. She enjoys rapid, fiery, emotional music, and her reaction is very marked. Wagner, Beethoven, Tschaikowsky, Schumann, Verdi, Franck are the composers she likes best.

Fig. 18. Performer S

	POOR 1-10	INF 11-30	L AV. 31-50	H.AV. 51-70	EX. 71-90	SUP. 91-100	
PITCH						✓	CAPACITY
INTENSITY					✓		
TIME						✓	
CONSONANCE						✓	
MEMORY						✓	
IMAGERY			✓				
INT. CONT.			✓				
SER. ACT.			✓				
RHYTHM					✓		
MOTILITY			✓				
PURSUIT	✓						
SIM. REACT.					✓		
INTEL.							
TIME					3	1	PERFORMANCE
TONE-QUAL.					1	3	
INTENSITY					2	2	
RHYTHM					3	1	
ART. UNITY				2	1	1	

Performer S

Music played: March Wind (*MacDowell*)

Musical history: S's sister plays piano, and friends come to the home to play and sing. *S* hears about 15 concerts a year.

S has studied music in public school about ten years; has had 325 half-hour piano lessons; one semester elementary harmony.

He plays in public at least once a month; *S* does not sing but he carries a tune with ease. He improvises and plays by ear.

S is rather vague as to his musical preferences, although Wagner and Brahms appeal to him. His reaction to music is "sort of an inspiration." He is considering music as a possible profession.

Fig. 19. Performer T

	POOR 1-10	INF. 11-30	L. AV. 31-50	H.AV. 51-70	EX. 71-90	SUP. 91-100	
PITCH					✓		CAPACITY
INTENSITY						✓	
TIME					✓		
CONSONANCE					✓		
MEMORY					✓		
IMAGERY						✓	
INT. CONT.					✓		
SER. ACT.					✓		
RHYTHM					✓		
MOTILITY				✓			
PURSUIT		✓					
SIM. REACT.					✓		
INTEL.			✓				
TIME			2	1	1		PERFORMANCE
TONE-QUAL.			1		3		
INTENSITY			1	2	1		
RHYTHM				2	2		
ART. UNITY		1	1	2			

Performer T

Music played: To Spring (*Grieg*)

Musical history: T's father and two brothers play, and music is a constant part of her home life. She hears about six good programs a year.

Six years of public school music; 500 half-hour piano lessons; and 1 semester elementary harmony constitute *T's* musical training.

T plays in recitals two or three times a year, and sings in choir, chorus, and glee club.

She likes music that is "dreamy, sentimental, sad." She is taking music because she likes it, and because she is "lost" without it.

Fig. 20. Performer U

		POOR 1-10	INF. 11-30	L. AV. 31-50	H. AV. 51-70	EX. 71-90	SUP. 91-100
CAPACITY	PITCH						✓
	INTENSITY						✓
	TIME						✓
	CONSONANCE					✓	
	MEMORY						✓
	IMAGERY						✓
	INT. CONT.					✓	
	SER. ACT.					✓	
	RHYTHM					✓	
	MOTILITY			✓			
	PURSUIT	✓					
	SIM. REACT.					✓	
	INTEL.						✓
PERFORMANCE	TIME		2			2	
	TONE-QUAL.				2	2	
	INTENSITY			1	1	2	
	RHYTHM		1			3	
	ART. UNITY		1		3		

Performer U

Music played: Prelude in C♯ Minor (*Rachmaninoff*)

Conditions of performance: U's playing was characterized by an immature conception of the music she attempted. She handled the notes of her music excellently, and her tone-quality was full and rich throughout. But *U* was concerned with the technical side of her music, and missed completely its emotional possibilities. Undoubtedly that will come with *U's* further development, but it accounts for the relatively low marks *U* received in artistic unity.

Musical history: In *U's* home, her father plays piano, violin, guitar, banjo, mandolin, ukulele, piccolo, and her father and aunt sing. Besides the music they make themselves, friends and semi-professional players are visitors in their home. *U* hears about 4 good programs a year.

U has had 12 years' public school music; 800 half-hour lessons on the piano; 10 half-hour violine lessons; and 1 semester elementary harmony.

U enjoys most piano and violin recitals. Her sensitiveness to musical impressions is keen. "After I hear music, I feel inspired for weeks afterward to work harder. I feel as if I were walking on air." *U* is considering making music her profession.

Comparison of Capacity and Performance Ratings

The measurement of the relationship—the correlation—of the two series of tests was made in every case by the method of rank differences. The students were ranked in order of merit from 1–20 in each test for the purposes of comparison with every other test. The statistical formula used is the one deduced by Spearman in which $\rho = 1 - \frac{6 \text{ Sum } D^2}{n(n^2 - 1)}$, when D represents any difference in the rank of an individual in the two series, and n the number of cases.

This method of correlation is useful only under certain conditions. *Rugg* (23, p. 256) lays down the following rule: "Use the rank method when *N* is small (say, less than 30) . . . the result in cases of this sort can at best only indicate the existence of correlation, and not the closeness of the relationship. Therefore we must be extremely cautious in our interpretation of rank correlations, or of any correlations computed for a small number of cases."

Division of capacity tests into sensory and motor groups. In ranking the students for proficiency in the capacity tests, a clearer picture of the results is gained if the tests are divided into two groups, sensory and motor. The sensory tests are those dealing primarily with discrimination and perception, and include the tests of pitch, intensity, time, consonance and memory. The motor tests are primarily concerned with muscular action, movement. They include pursuit, serial action, motility as shown by the tapping test, simple reaction, and rhythm. These divisions are arbitrary and do not represent all the facts. There may be supplementary motor elements involved in the sensory tests, as for instance, the tendency on the part of a subject in taking the test for discrimination of time to tap his finger, nod his head, or move his hand, as an aid to the perception of the small differences. And many sensory elements are involved in the motor tests, such as the dependence of the hand-movement on the eye in the pursuit and serial action tests, and on the ear in the rhythm test. But

since the results of the measurements attempted in the first series are given in sensory terms, while those of the second are in motor terms, for the sake of clearness, the two may be separated in this discussion.

There are two tests which are still more definitely "border-line cases" than the ten already mentioned. Proficiency in intensity control is equally dependent on the discrimination of small differences in intensity, and the ability to make fine muscular adjustment. In the test of auditory imagery there is no accurate means of determining how many ramifications of motor imagery, unrecognized by the observer, add to the distinctness of the image which he calls auditory. The intensity control test has been assigned to the motor group, the auditory imagery to the sensory.

Method of ranking the capacity tests. The students were ranked in the sensory and motor tests by the same method. The actual records of the students in each test were arranged in order of merit, and numbers from one to twenty were assigned to indicate the student's position in the series. It was useful also to know the rank of the student in sensory capacities as a whole, and motor capacities as a whole. Ranks for the composite motor charts were obtained by averaging the ranks received in the selected group for each of the six motor tests. Ranks for the sensory chart were determined by averaging the selected group ranks for the pitch, intensity, time, consonance, and memory tests. The imagery score, being a subjective rating of himself by each student, is not included in the sensory chart, since it is not on a basis comparable with the other sensory tests.

Method of ranking the performance ratings. For ranking the performance ratings, a plan similar to that of *Miner* (17) was used. The ratings assigned by the four judges to every student were averaged. The student's rank in each criterion was determined by arranging these averages in order of merit and assigning to them rank numbers from 1 to 20. A rank for performance as a whole was obtained by averaging the ranks every student received in each of the 5 criteria. This composite rating of per-

formance is referred to in all graphs and tables as the performance chart.

Evaluation of the performance ratings. After the first afternoon's performance test, control judges were introduced so that their judgments of the players could be used as a basis of comparison and check on those of the four expert judges. This group was composed of professed non-musicians. There were always four inexpert judges in the group, on two occasions, five, but the personnel did not remain constant throughout the tests. There were in all seven inexpert judges: Professors Mabel C. Williams, Warner Brown, F. B. Knight, J. B. Morgan, and Dr. T. P. Brennan, all members of the university faculty, together with Rev. Walter Schafer, and Mrs. Merritt Fossler.

A comparison of the expert and inexpert judgments will be made in three ways—the distribution of the marks given by each group; the agreement of judgments within the groups and between the groups; and the intercorrelation of the student's ranks in the five criteria based on the ratings made by each group of judges.

Distribution of marks given by each group. There were in all three hundred judgments made by each group of judges during the performance tests at which both expert and inexpert judges rated the players. Of the actual marks given by the expert judges, 9 per cent placed the performer in the superior groups, 32 per cent in the excellent, 45 per cent in the average, 12 per cent in the inferior, and 9 per cent in the poor; of those assigned by the inexpert judges, 8 per cent placed the performer in the superior groups, 25 per cent in the excellent, 51 per cent in the average, 14 per cent in the inferior, and 3 per cent in the poor. These results are presented in Fig. 21. This graph shows that the inexpert judgments are distributed in a curve somewhat more similar to that of the theoretical distribution of marks in a large unselected group, than do the expert judgments: but the difference is trifling. That this is not an unselected group is shown by the broken line, which represents the actual distribution of the results of the five sensory capacity tests given these students.

These five tests may be used as criteria since they are objective and have a high degree of precision in their measurement. Forty-nine per cent of the marks lie in the superior group, 27 per cent in the excellent, 16 per cent in the average, and 5 per cent in the poor. Judgments made on the performance of such a superior group would be expected to skew toward the higher markings.

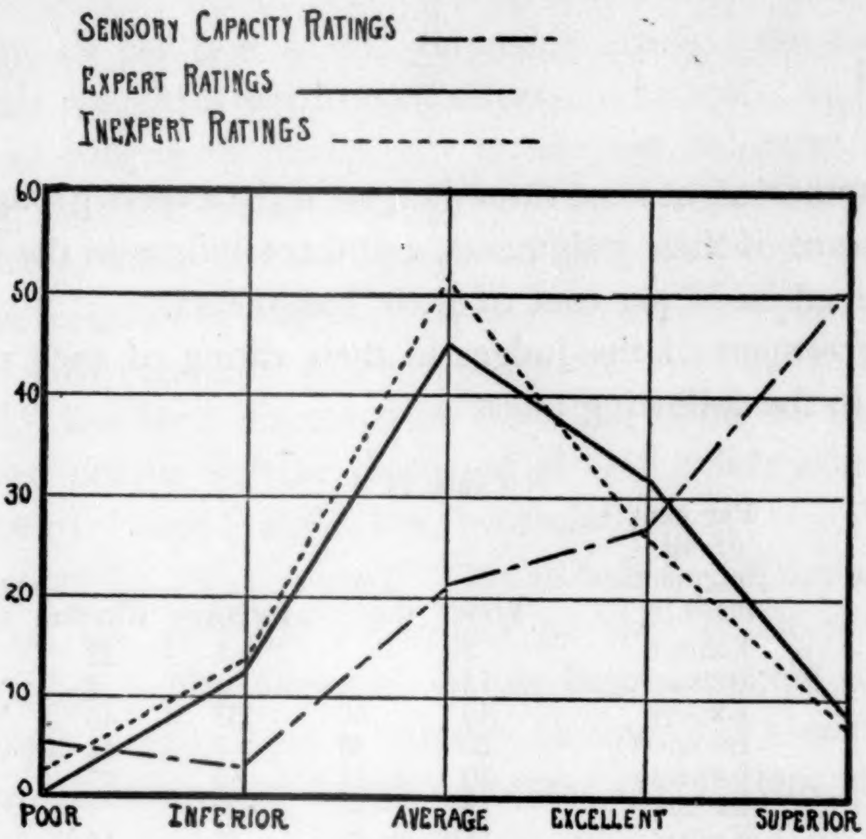

Fig. 21

The expert judgments recognize somewhat more adequately than the inexpert the selected nature of this group of performers.

Agreement among the judgments made by the two groups. Agreement in the ratings of the judges is a mark of reliability in judgment. It tends to show that the scale used is interpreted in the same way by all the judges, and that the factors in performance which are being rated appear to all the judges in the same light. Perfect reliability would suppose perfect agreement, but that is difficult to attain in a rating scale dependent on the vagaries of human judgment. In this study we can only show the relative reliability of the two sets of judgments.

In the following table is shown the agreement between the expert and inexpert judges within their own group.[1]

TABLE I

Type of division among the judges	Per cent of judgments made by experts	Per cent of judgments made by inexperts
4–0	7	4
3–1	36	23
2–2	15	20
2–1–1	33	51
1–1–1–1	9	3

Or, to summarize, at least three judges in the expert group agreed in 43 per cent of their judgments, and three judges in the inexpert group agreed in 27 per cent of their judgments.

The agreement of the judges in their rating of each criterion is shown in the following table:

TABLE II

Type of division among the judges	Per cent of all judgments made by	Time	Tone quality	Intensity	Rhythm	Artistic unity
4–0	Expert	5		5	25	10
	Inexpert	13			7	
3–1	Expert	40	60	35	40	25
	Inexpert	20	33	7	41	20
2–2	Expert	20	15	10	15	10
	Inexpert	13	33	20		13
2–1–1	Expert	15	20	45	15	50
	Inexpert	53	33	60	40	53
1–1–1–1	Expert	20	5	5	5	5
	Inexpert			13	7	7

Again summarizing, at least three expert judges agree in estimation of time in 45 per cent of their judgments, of tone-quality in 60 per cent, of intensity in 40 per cent, in rhythm 65 per cent, and in artistic unity, 35 per cent; while three inexpert judges agree in their estimation of time in 33 per cent of their judgments, tone-quality 33 per cent, intensity 7 per cent, rhythm 47 per cent, and artistic unity 20 per cent. It is interesting to note that the degrees of artistic unity were not defined in the scale, that

[1] The agreement of all four judges is designated 4–0, the agreement of any three, 3–1, the agreement of any two, 2–2, or 2–1–1, and the total lack of agreement, 1–1–1–1.

definition being purposely left for each judge to decide for himself. The agreement of the expert judges is less in this criterion than any other.

As for agreement between the groups, in 1 per cent of all judgments made, four expert judgments coincided with four inexpert judgments; in 22 per cent of all judgments made, only three expert judgments out of four coincided with three inexpert judgments; in 19 per cent of all judgments made, only two expert judgments coincided with two inexpert judgments; and in 6 per cent of all judgments made, only one expert judgment coincided with one inexpert judgment. In 51 per cent of all the judgments made, there was no agreement between the groups.

Intercorrelation of the five criteria. Intercorrelation of the five criteria, with reference to the size of the correlations and their "spread," has been discussed in Part III. Size of the correlations need not be further discussed at this point, aside from a definition of "high" and "low" correlations.

Rugg (**23**, p. 256) says: "This definition of limits depends largely on the personal experience of the person making the interpretation. For example, it has been common for certain educational investigators arbitrarily to interpret a coefficient of .25 as an indication of "high" positive correlation, and one of .40 as "very high." Others would interpret .25 as very low, and .50 as "marked" or "somewhat high." Certainly our educational conclusion must be colored by our arbitrary definition of such a coefficient. The experience of the present writer in examining many correlation tables has led him to regard a correlation as "negligible" or "indifferent" when r is less than .15 to .20; as being "present but low" when r ranges from .15 or .20 to .35 or .40; as being "markedly present" or "marked" when r ranges from .35 or .40 to .50 or .60; as being "high" when it is above .60 or .70. With the present limits on educational testing, few correlations in testing will run above .70, and it is safe to regard this as a very high coefficient."

From this definition it will be seen that all the correlations presented in the following tables are very high.

The factor of spread was also discussed in Part III. There is comparatively narrow range of difference between the intercorrelations of the performance criteria as rated by both experts and inexperts.

The following table presents the correlations between the performance criteria as rated by the expert judges.

TABLE III

	Tone-quality	Intensity	Rhythm	Artistic unity
Time..........	.73, p.e., .07	.85, p.e., .04	.82, p.e., .04	.92, p.e., .009
Tone-quality		.68, p.e., .08	.64, p.e., .08	.75, p.e., .07
Intensity.......	.68, p.e., .08		.72, p.e., .07	.96, p.e., .007
Rhythm.......	.64, p.e., .08	.72, p.e., .07		.82, p.e., .04
Artistic unity...	.75, p.e., .07	.96, p.e., .007	.82, p.e., .04	

The next table presents the correlations between the performance criteria as rated by the inexpert judges:

TABLE IV

	Tone-quality	Intensity	Rhythm	Artistic unity
Time...........	.86, p.e., .04	.87, p.e., .04	.84, p.e., .04	.86, p.e., .04
Tone-quality		.64, p.e., .08	.63, p.e., .08	.84, p.e., .08
Intensity.........	.64, p.e., .08		.84, p.e., .04	.91, p.e., .02
Rhythm.........	.63, p.e., .08	.84, p.e., .04		.86, p.e., .04
Artistic unity.....	.64, p.e., .08	.91, p.e., .02	.86, p.e., .04	

The above tables show that the expert judges rate each criterion scarcely more independently than do the inexpert group.

The validity of the judgments. Table V shows that the ratings of the expert judges may be considered more valid for the purpose of this investigation. They cannot be shown to be absolutely reliable, nor can it be demonstrated that the judgments of this group of musicians is better or worse than those of any other similarly trained group. But when contrasted with the ratings made by a group untrained in musical judgment, the ratings of the musicians are more reliable because first, they recognize more definitely the selected quality of the group rated; and second, because they agree in a higher per cent of cases. If we use *Rugg's* terminology, and speak of a correlation of .40 to .50 as being marked, the performance charts rated by the expert judges show significant correlation with the sensory data as a whole, and with memory as a particular sensory capacity; and with motility, simple reaction, and rhythm in the motor group. The

correlation of the sensory data as a whole with performance is markedly higher than that of the motor data. In none of the tests except serial action is there negative correlation with the performance ratings. Intensity, intensity control, and pursuit may be considered negligible correlations, while correlations with pitch, time, consonance, and imagery are present, but low.

The performance charts giving ratings by the inexpert judges show no correlation with either the sensory data as a whole or any individual sensory test. With pitch, time, and imagery, the

TABLE V

	Performance	
	Inexpert judgments	Expert judgments
Sensory chart	.05, p.e., .17	.54, p.e., .1
Pitch	—.03, p.e., .17	.27, p.e., .14
Intensity	.12, p.e., .17	.17, p.e., .14
Time	—.11, p.e., .17	.23, p.e., .14
Consonance	.18, p.e., .17	.28, p.e., .14
Memory	.06, p.e., .17	.47, p.e., .12
Imagery	—.11, p.e., .17	.24, p.e., .14
Motor chart	.44, p.e., .13	.17, p.e., .16
Intensity control		.18, p.e., .17
Pursuit	.2, p.e., .16	.18, p.e., .17
Motility	.65, p.e., .09	.43, p.e., .13
Simple reaction	.67, p.e., .09	.48, p.e., .12
Serial action	—.24, p.e., .16	—.33, p.e., .14
Rhythm	.38, p.e., .15	.47, p.e., .12

correlation is slightly negative. On the other hand, the correlation with the motor data is significant, and the correlations with motility and simple reaction is startlingly high. There is also correlation with rhythm, although it is not high.

These correlations may give us a clue to the basis on which a listener, untrained in music, judges musical performance. The more musical factors such as dynamics, phrasing, grasp of the formal content of the piece, nice variations in tempo—all of which demand sensory training for their perception—are negligible in comparison with motor, or technical skill. This was also demonstrated in the rating of the individual performers by the inexpert judges. Performer *H* was rated low in all criteria because of the peculiar heaviness of her " touch," and its apparent lack of flexibility. Performer *K*, whose playing from the standpoint of the experts was unsatisfactory musically, was ranked

first by inexpert ratings, because of the spurious brilliance of her octave passages.

That all criteria were judged by the inexpert judges on the same motor basis is shown by Table VI, in which the correlations of expert judgments with the same factors are presented as a contrast. While in the latter group tone-quality correlates highly with both motility and simple reaction, there is wide variation in the other correlations. The relation of tone-quality to motility will be discussed later and need not be dwelt upon at this time.

We may venture to suggest, then, that a concert pianist, desiring popularity with his audience, 90 per cent of whom are musically untrained, should include in his program several technically brilliant pieces, even though they be not strictly in harmony with the plan of the program. The next box-office receipts will justify his choice.

TABLE VI

	Time	Tone-quality	Intensity	Rhythm	Artistic unity
Motility					
Expert judgment ..	.36, p.e., .14	.63, p.e., .09	.21, p.e., .15	.32, p.e., .14	.38, p.e., .14
Inexpert judgment ..	.61, p.e., .09	.91, p.e., .06	.63, p.e., .09	.61, p.e., .09	.64, p.e., .09
Simple Reaction					
Expert judgment ..	.44, p.e., .12	.68, p.e., .08	.47, p.e., .12	.43, p.e., .12	.32, p.e., .14
Inexpert judgment ..	.74, p.e., .08	.65, p.e., .09	.58, p.e., .1	.57, p.e., .1	.58, p.e., .1

Correlation of each criterion with the capacity tests. Table VII presents the correlation of each criterion with each capacity test.

TABLE VII

Performance	Time	Tone-quality	Intensity	Rhythm	Artistic unity
Pitch	.31, p.e., .14	.38, p.e., .13	.31, p.e., .14	.35, p.e., .13	.39, p.e., .12
Intensity	.20, p.e., .10	.12, p.e., .15	.21, p.e., .14	.34, p.e., .13	.28, p.e., .14
Time.	.10, p.e., .15	.27, p.e., .14	.14, p.e., .14	.34, p.e., .13	.28, p.e., .14
Consonance. . .	.31, p.e., .14	—.03, p.e., .15	.28, p.e., .14	.47, p.e., .12	.39, p.e., .12
Memory	.50, p.e., .11	.32, p.e., .14	.56, p.e., .10	.36, p.e., .13	.54, p.e., .10
Imagery	.06, p.e., .15	.18, p.e., .14	.11, p.e., .15	.17, p.e., .14	.21, p.e., .14
Intensity control	.41, p.e., .15	.15, p.e., .17	.33, p.e., .16	.05, p.e., .17	.23, p.e., .16
Pursuit	.21, p.e., .15	.37, p.e., .14	.01, p.e., .16	.28, p.e., .14	.16, p.e., .15
Motility	.36, p.e., .14	.63, p.e., .09	.21, p.e., .15	.32, p.e., .14	.38, p.e., .14
Simple reaction	.44, p.e., .12	.68, p.e., .08	.47, p.e., .12	.43, p.e., .12	.32, p.e., .14
Serial action.	.17, p.e., .15	.12, p.e., .16	.39, p.e., .13	—.29, p.e., .14	—.22, p.e., .15
Rhythm	.50, p.e., .09	.50, p.e., .09	.55, p.e., .09	.48, p.e., .10	.62, p.e., .08

Relation of individual capacity tests to performance. In Table VIII is presented a summary of the most significant correlations between the five criteria of performance and the musical capacity tests. Although there is low correlation when ρ ranges from .15 to .35 or .40, only the " marked " correlations have been considered—those ranging above .40. In interpreting these correlations, the writer realizes the hazardous nature of the task. Since no previous analysis of such relationships has been made, the present attempt is at best largely colored by the method of obtaining, and the nature of, the data at hand. But in the hope that these suggestions may be used as a point of departure for further investigation, they are included in this study.

TABLE VIII. *Criteria of performance*

Capacity tests	Time	Tone-quality	Intensity	Rhythm	Artistic unity
Consonance				.47, p.e., .12	
Memory	.50, p.e., .11		.56, p.e., .1		.54, p.e., .1
Intensity control	.41, p.e., .14				
Motility		.63, p.e., .09			
Simple reaction..	.44, p.e., .12	.68, p.e., .08	.47, p.e., .12	.43, p.e., .12	
Rhythm	.50, p.e., .11	.50, p.e., .11	.55, p.e., .1	.48, p.e., .12	.62, p.e., .09

Time in performance. By Table VIII it will be seen that time in performance is most related to the capacity tests of memory, intensity control, simple reaction, and rhythm. We should expect relationship between time and rhythm (12); a musical memory might include time as one element of the whole; and good reaction-time, as a quality of action in general, characterizes any given muscular response (15). But the relation to intensity control is not so apparent without a more detailed analysis of the test itself.

In this test the subject sits with his eyes closed listening to the tone sounding in a telephone receiver, which tone the experimenter produces by sliding a contact rider over a series of brass contacts. When the contact point producing the tone of desired intensity is reached, the experimenter taps on it three times with the contact rider. The subject then attempts to match the tone by sliding his contact rider along the scale. When he reaches the intensity which seems right to him, he also taps three times. There are at least three factors in the test which stand out in the

introspections of the subjects—the effort to remember the given intensity as the experimenter presented it, the muscular adjustment necessary to slide the contact rider just to the right contact point and no farther, and the feeling that it is necessary to slide the contact rider over the scale at exactly the speed which the experimenter did. The latter point was not characteristic of all the introspections, but it was general enough to lead the writer to try varying the speed with which she slid the rider across the scale. There was an invariable tendency on the part of the subject to imitate her speed. Thus the duration of time for both motions tended to be the same, and in several cases, the subject depended on equaling the experimenter's time to find the given intensity rather than on his memory of the tone. While the time factor was prominent in the consciousness of only a few of the subjects, there is evidence that it was present in all cases, functioning as a determiner of the muscular innervation.

As further evidence of the relation of time and rhythm to the ability of the subject to make a good record in the test, the correlation of the rhythm test with intensity control is .47, p.e. .12.

It is also interesting to note that intensity in performance and the sensory test of intensity have little relation to the test of intensity control, but both intensity control and intensity in performance have a high correlation with tonal memory. In attempting to analyze these facts, we realize that in the Seashore test of intensity the differences in the strength of the tone become so small that for some observers they are below the threshold of perception. The test thus becomes in part a measure of the threshold for intensity. On the other hand, the steps in the intensity control test are above the threshold for all normal ears, and are easily perceptible (39), so that the subliminal factor is ruled out. In the test for intensity discrimination, the intensities to be compared are presented to the observer in immediate succession. But in the intensity control test, a time interval of from five to ten, even more, seconds elapses between the standard intensity presented by the experimenter and the intensity judged by the observer to be of equal strength.

The significance of a lapse of time in sensory discrimination has been analyzed at length by *Whipple* (38) and *Fernberger* (8), and it is probably at this point that the most striking difference occurs in the two tests; Whipple finds that the most favorable time interval for auditory discrimination is 2 sec. In judgments such as this which tend to be immediate, the memory image does not necessarily serve as a basis of comparison although it may be present. Judgment may be based instead on kinesthetic factors. Also in judgments of difference made after a longer interval, the memory image may be lacking as an active element of consciousness. But in judgments of equality made after a ten or twenty second interval has elapsed, the memory image plays an important part. " In equality judgment there is an alternation of images, and a real comparison " (8, p. 9). *Wolfe* claims that after a 10 to 20 sec. interval has elapsed the memory image not only ceases to disintegrate, but there is positive renewal of it, and this renewal aids correct judgment.

If these findings be true, we should expect significant correlation with both imagery and memory, since in the intensity control test, an equality judgment must be made after a lapse of ten or more seconds. The correlation with imagery is .48, p.e. .11, while that with tonal memory is .68, p.e. .08. Whether the correlation of intensity in performance with tonal memory is due to a common element of imagery, the writer is not prepared to say. But in the light of the above facts such an explanation might be plausible.

Tone-quality. Tone-quality shows the closest relationship to the three motor tests of motility, simple reaction, and rhythm, other than that it is evidence of the " halo " error on the part of the judges.

Simple reaction may be related to tone-quality for two reasons: first, because it correlates highly with motility, .58, p.e. .10; and second, because it is indicative of speed of muscular adjustments. *Ladd and Woodworth* (15, p. 498) say of it: " In ordinary life, while reactions essentially like the simple discriminative and associative reactions of the experimenters are common enough, they

do not occur in isolation, but as parts usually of continued performances. . . . Both overlapping and reaction to large units enter into such skilled performances as a typewriter writing from copy, or a musician playing from score. These performances consist of a series of discriminative reactions; and yet their speed may be such that only an eighth or a tenth of a second is occupied by each movement—much less than the time of a discriminative reaction. The high speed is due partly to apprehending and reacting to phrases rather than to single notes, words, or letters; and partly to carrying on processes of apprehension and movement simultaneously." Such speed of reaction approximates more nearly response to a simple stimulus than to one which is very complex, and probably explains the relationship of simple reaction time to skill in the rapid muscular adjustments which are necessary to secure good tone-quality.

To justify the third correlation, we must again turn to a closer analysis of the test of motility, the tapping test. In it, the subject is required to make a simple tapping motion with a telegraph key held between his thumb and forefinger at maximum speed for an interval of five seconds. To throw light on the muscular conditions which make for proficiency in the test, *Ream* (19) has quoted the introspections of adult observers who repeated the test daily under uniform conditions for a period of twenty days. Miss *K* reports: "I do better when I apply the power where it ought to be, if I can keep my arm from becoming too rigid. I make the rest of my body tense; my right arm only is not rigid." Mr. *H* reports: "I think the 'low' days are accounted for by the stiff arm I get from playing handball." The group of students selected for this study consistently reported to the writer during any temporary lowering of their records that their arms "grew stiff," "the muscles were rigid," it was "hard to move fast." In every case the student whose arm was relaxed and free was the one who tapped with most speed and regularity.

Now these muscular conditions are analogous to those of a pianist when he is securing a "good" tone on his instrument. We have the testimony of no less an artist than Ossip Gabrilo-

witsch: "Touch is the distinguishing characteristic which makes one player's music sound different from that of another, for it is touch that dominates the player's means of producing dynamic shading, or tone quality. . . . The full-arm touch, in which I experience a complete relaxation of the arm from the shoulder to the finger tips, is the condition which I employ at most times. . . . You will observe by placing your hand upon my shoulder that even with the movement of the single finger, a muscular activity may be detected at the shoulder. This shows how completely relaxed I keep my entire arm during performance. It is only in this way that I can produce the right kind of singing tone in cantabile passages. . . . The arm should feel as if it were floating, and should never be tense" (5, p. 125). Leopold Godowsky also supports this statement: "In this method of playing ('weight' method) the fingers are virtually 'glued to the keys' in that they leave them the least possible distance in order to accomplish their essential aims. This results in no waste motion of any kind, no loss of power and consequently the greatest possible conservation of energy. In this manner of playing, the arm is so relaxed that it would fall to the side if the keyboard were removed from beneath it" (5, p. 137).

Since motility correlates with musical training only .22, p.e. .16, which we may regard as a correlation of little significance, and since it correlates with tone-quality in performance .63, p.e. .09, which is a high correlation, it would seem as though we had in the tapping test a real gauge of capacity for an important element in performance. While the ability to produce good tone-quality may improve with musical training, the tapping test appears to give a good index to the amount of improvement that may be expected,—an index that is, to the physiological limit of the performer to respond to the technical demands of good tone-production, and to maintain the relaxed arm necessary for octave and passage work. In summarizing the results of practice in the tapping test, *Ream* (19) says: "Where improvement was found, it was due to improved technique (in handling the telegraph key), less wasted effort, a decrease of variability, better attitude.

. . . Where improvement did *not* occur the observers developed good technique the first day, were quite regular in their performance, and put forth their maximum effort. . . . Low variability (in the test) is a sign that the effect of practice has already been accomplished, and there is no chance for further improvement. Of two persons having the same average score, the one with the high variability has better chance for improvement. . . . The effect of practice is very important in considering just what the test measures. If the ability required in the test is fundamental rather than necessary, learning will play a very small part and there will be very little improvement with practice. And this is seemingly just what the practice experiment showed. No improvement would indicate that a basic motor capacity is being tested."

Keeping these findings in mind, the tapping test may be applied with real profit to the music studio. If, in taking the test for the first time, the student shows low variability in the number of taps per second, and his speed is high, one of the hardest phases of his technical struggles—relaxation—may be assumed to be over, either through wise instruction and practice, or through a certain fortunate neuro-muscular organization with which he was born. If his variability is low, but his speed is also low, it may be considered an indication of the type of mechanical work which may be expected from him; *i.e.,* that there is less evidence of needed capacity than the first student possesses for the freedom and speed necessary for brilliant performance. But this second student may do very satisfactory work in a type of music which does not demand brilliancy from him. If in taking the test, his record shows great variability, with the speed either high or low, the student will require the sagacious counsel and wise direction of his teacher along technical lines. Improvement may be expected, and the tapping test may be valuable as an objective measure of progress. When the maximum improvement has been made, the tapping record will show very low variability, with the speed either low or high, according to the neuro-muscular organization of the student.

Intensity. The tests most related to intensity are memory, simple reaction, and rhythm. The relationship to memory has already been discussed in connection with the test of intensity control. Rhythm might again be interpreted as evidence of the "halo" error. Good reaction-time is shown, by its correlation with four criteria of performance, to be essential to performance as a whole, and probably is not more significant in its correlation with intensity than with the other criteria. Probably the correlations within the group are due largely to a general capacity for precision.

Rhythm. The correlation of rhythm in performance with consonance is one of those anomalies about which the writer cannot venture anything but speculation. The literature on consonance offers no help. If more experimental data could be found on the affective-tone which accompanies a recognition of consonance and dissonance, together with the organic states characteristic of the affective-tone, it might be possible to relate these to similar organic states in the perception and execution of rhythm. There is no evidence at the present time for such an assumption. The relationship is only conjecture.

The relation of rhythm in performance to the rhythm test is sufficiently satisfactory to justify the prognostic use of the rhythm test. The test itself is not wholly satisfactory in its present stage, on account of the lack of some simple and accurate means of recording the patterns which the subject taps in response to the stimulus pattern. The graphic record, as tried out with this apparatus, requires too much time to read, and the errors recorded by that means are at present unpenalized in the grading system devised by Révécz.[1] But its high correlation with performance throughout shows it to be of importance in indicating the student whose playing possesses artistic merit, and it should be thoroughly standardized for such use.

Artistic unity. The sensory test of memory and the motor test of rhythm correlate most highly with artistic unity. Since tonal

[1] These difficulties have been overcome by the standardized test referred to in Section II.

memory probably involves some of the elements common to the other sensory tests, and rhythm is perhaps the most outstanding of all the motor elements by which one judges performance, we have in these two tests rather a good indication of the probable artistic performance of the student. It is never safe to make positive prognostications on one or two tests, but in judging a student by those which are most relevant to artistic performance, we may be given an indication of the student's real musical ability.

Negative correlations. A negative correlation may be as efficacious in evaluating a test for a given purpose as a positive correlation. This would seem to be true in the case of serial action. It is the only motor test which consistently appears to have no relationship to any of the chosen criteria of musical performance. It is interesting to find this true, since all of the motor tests were chosen at a hazard from among a number of others, with the hope that they might prove of value in indicating certain performance capacities; yet without any preconceived idea in the mind of the writer as to just which capacities they would indicate. Of this battery of motor tests, serial action is one which should not have been chosen, if we are to be guided by the results.

At first thought, the test would seem to be analogous to the mental processes involved when reading new music. That is, a visual signal,—in the case of music, notes; in the case of the test, lights,—is to be translated into motor results,—in both cases a certain motion of four fingers on movable keys. Yet on closer analysis the similarity of the conditions is a superficial one. The musician at the piano is guided in his task by that most valuable of all aids, his ear. At the typewriter he has only his powers of observation on which to depend. It is even possible that the similarity of the test to the outer conditions of reading music may be one of the hampering factors in securing test results. So dependent has the musician become on the sound which ordinarily accompanies the visual signal and motor reaction that the lack of it disconcerts him and retards him in his ability to adjust to the test. It would be an experiment worth trying to attach both auditory and visual stimuli at the same time to the four type-

writer keys in order to compare with the results secured from visual stimuli alone or auditory alone.

Since the test in its present form seems to require for its successful operation the alert, objective type of mind, rather than the subjective type usually accredited to musicians, it is not worth while to include it in a battery of tests designed to throw light on performance capacity. It has its useful plan among tests of motor ability, but as a test for this particular ability it serves no purpose.

The Relation of Training to Performance

While in this investigation there has been no extensive study made of the relative importance of training and capacity in musical performance, it seems advisable to present the material at hand, and to suggest lines of further study in this field. Such study must be made before any absolute conclusions can be drawn regarding the definite prognostic value of music capacity tests.

Correlations of training with performance and capacity. In Table IX are presented the correlations of the performance chart with sensory capacity, motor capacity, and musical training. By

TABLE IX

	Sensory chart	Motor chart	Training
Performance chart	.54, p.e., .10	.42, p.e., .13	.65, p.e., .09

musical training is meant simply the actual number of half-hour lessons the student has had, without regard for the quality of the instruction. The number of hours of instruction for each student is ranked in order of amount and numbers from one to twenty assigned to indicate his position in the series.

Since the Spearman correlation formula does not allow of fine quantitative comparisons, it is impossible to say just how much more important is the correlation of performance with training than that of performance and sensory capacity. That training plays a larger part in performance than it does in the capacity tests is shown in Table X, which presents the correlations of training with sensory capacity, motor capacity, and the five criteria of performance.

In Table X, also, is shown the relation of training to proficiency in each capacity test. In this group training is significant in the pitch test, the memory test, the imagery test, intensity control, simple reaction, and rhythm. The correlation with the rhythm test is very high,—so high that we can in no way assume that proficiency in this test is independent of previous training. The

TABLE X

		Training
Capacity	Sensory chart	.39, p.e., .12
	Motor chart	.32, p.e., .13
	Pitch	.42, p.e., .12
	Intensity	.25, p.e., .14
	Time	.38, p.e., .12
	Consonance	.02, p.e., .17
	Memory	.55, p.e., .1
	Imagery	.52, p.e., .11
	Intensity control	.60, p.e., .09
	Pursuit	—.05, p.e., .17
	Motility	.22, p.e., .16
	Simple reaction	.45, p.e., .12
	Serial action	.18, p.e., .14
	Rhythm	.74, p.e., .07
Performance	Time	.63, p.e., .09
	Tone-quality	.55, p.e., .1
	Intensity	.54, p.e., .1
	Rhythm	.46, p.e., .12
	Artistic unity	.59, p.e., .09

motor tests of pursuit, motility, and serial action do not correlate with musical training. But neither do pursuit and serial action correlate with performance. On the other hand, motility correlates so highly with performance (see Table VII) that we have evidence that it is a basic test of performance ability independent of musical training.

In Table XI is presented the same sort of summary that is to be found in Table VIII, with the correlations of training with each capacity test and each performance criterion added for comparison. There is no attempt at interpretation of the contrast presented by these figures. The application of statistical formulae to them in order to determine the exact worth of training is unwarranted because of the obvious inadequacy of data on training.

Problems suggested by these data. A casual reader in glancing through the above correlations would find himself tempted to

conclude that performance ability depended not so much on the musical capacity of the student as on the training which he had received. On the other hand, could not the inference be drawn that the student who had sought musical training eagerly and continued it over a long period of time was the student so equipped in sensory and motor capacities that musical training was one of his fundamental needs? In other words, his tonal memory need not be good because he had received a certain amount of training;

TABLE XI

Criteria of performance

	Training		Time		Tone-quality		Intensity		Rhythm		Artistic unity	
	Rho	P.E.	Rho	P.E.	Rho	P.E.	Rho	P.E.	Rho	P.E.	Rho	P.E.
Training......			.63	.09	.56	.10	.56	.10	.46	.12	.60	.09
Consonance	.01	.16							.47	.12		
Memory......	.55	.10	.50	.11			.56	.10			.54	.10
Intensity control	.60	.09	.41	.14								
Motility......	.22	.15			.63	.09						
Reaction......	.45	.12	.44	.12	.68	.08	.47	.12	.43	.12		
Rhythm......	.74	.07	.50	.11	.50	.11	.55	.10	.48	.12	.62	.09

but because he is possessed of a keen tonal memory, he naturally gravitates toward thinking and working with tones. This theory would make of sensory and motor capacity a factor in the natural selection of the music student,—the fittest who survive being those who have naturally had the greatest amount of training. Such a problem cannot be settled without studying the musical capacity and backgrounds of a number of students over a period of years.

Another question which must be answered is the influence of musical capacity on the response of the student to training. Does not the one with the greatest capacity make the most progress in training? By selecting a group of students with approximately the same amount of training, rating their ability to perform, and subjecting them to exactly the same kind of instruction for a period of time, their performance could be rated again at the end of the given period, and the capacity charts of those making the most progress compared with the others. Or this same experiment might be tried with profit on a group of children who had

had no previous training, but whose musical capacity had been adequately measured.

Summary, Conclusions, and Recommendations

In this study the records of twenty selected students of music in twelve musical capacity tests have been compared with ratings of their ability in actual musical performance. These ratings were made by trained musicians by means of a defined rating scale. The reliability of their judgments is examined by comparison with the ratings made by a group of psychologists, skilled in making judgments, but untrained in music.

The ratings of the musicians are more valid, because there is recognition in them of the selected quality of the group rated as shown by the distribution of the marks of the group in the capacity tests; and there is somewhat of an agreement in the ratings of the musicians although they are as subject to the "halo" error as those of the inexpert. The inexpert judges base their ratings of performance ability almost entirely upon the motor skill of the performer, rather than upon the more distinctly musical qualities of his performance. This contrast between expert and inexpert musical judgments suggests that in subsequent musical research it will be important to secure adequately trained musicians to coöperate in the planning and carrying out of procedure. Their greater understanding of their art amplifies and supplements significantly the scientific attitude of the psychologist. On the other hand, the capacity for fine analysis is one to be desired and cultivated on the part of the musician. The judgments of the non-musicians fell into a more nearly normal curve of distribution than that of the musicians because of just this ability. The former group of judges were trained in making critical analyses, and therefore, if the vernacular of the musician were at their command, would probably have made more accurate judgments than the musicians.

There are several obvious sources of error in this method (employed because none more adequate appeared feasible to the writer) of studying any possible relationship between musical

capacity and performance. The most fundamental of these is the much higher degree of precision to be found in the capacity ratings, which are impersonal and objective, than in the judgments of performance, which can only be personal and for the most part subjective. The writer is open to serious criticism for comparing two such unequal measurements on a mathematical basis. A correlation formula taking account of rank differences in two series of achievements was used to minimize this difficulty. Another misleading factor is the employment of a majority of pianists among the students chosen for a study which compares their sense of pitch and of consonance with their performance ability. Almost the last capacity a pianist depends on is pitch. His pitch in performance is automatically determined by his instrument. In the case of the violinists the pitch factor in playing was almost independent of any capacity of his to *perceive* pitch as shown by the capacity test. In the four cases under observation the pitch of the violin depended more upon the stage of training in which the violinist appeared to be, and not upon his inherent capacity. That is, the motor side of his ability to perform in pitch appeared to be under test, not his sensory capacity for pitch.

A third source of error may be found in the fact that in judging the value of talent charts, something less than a rating of 50 in percentile rank is sufficient for musical performances. Dr. Seashore is of the opinion that in all the musical talents a rating of 50 or, in special instances lower, may be entirely adequate for excellent performance and that it is unreasonable to look for close correlation between capacity and performance when the capacity is fully adequate to the demands of performance in an early period of training.

Within the reliability of the method used and the number of cases studied, there is evidence for the following tentative conclusions:

(1) The student with superior musical capacity records tends to rank higher in performance than the student with only average or low capacity records.

(2) The individual tests which give the highest index to performance ability are tonal memory, intensity control, motility, simple reaction, and rhythm, as shown by Table No. VIII.

(3) The criteria of performance to which the above tests are most closely related as shown by Table No. VIII are as follows:

Time: memory, intensity control, simple reaction, rhythm.

Tone-quality: motility, simple reaction, rhythm.

Intensity: memory, simple reaction, rhythm.

Rhythm: simple reaction, rhythm.

Artistic unity: memory, rhythm.

(4) The test of intensity control involves such large elements of the sense of time, memory, and imagery, that there is doubt of its efficacy as an adequate test of the ability to control fine shades of intensity in performance, as is suggested in *Miss Wickham's* article on this subject (39).

(5) There is good evidence of close relationship between tone-quality and the motility test.

(6) Serial action appears to have no place in a battery of motor tests designed to test musical performance.

(7) Musical training plays a larger part in the performance than it does in the capacity tests.

The function of this investigation has been primarily to act as an opening wedge in the field. It is a preliminary study of the relationship between musical capacity and performance, and can make no permanent claims for itself. It is to be hoped that it will prove suggestive to the psychologist interested in music, and will stimulate the musician to seek a firmer psychological basis for his art.

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A REPORT OF THREE SINGING TESTS GIVEN ON THE TONOSCOPE

BY

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Historical; present form of the tests: apparatus and method, singing key and control of voice, singing interval, singing the keynote; discussion of some factors involved: singing key, voluntary control of pitch, singing interval; inter-relation of the tests; bibliography.

The three singing tests most commonly given by means of the tonoscope are singing keynote, singing interval, and discriminative control of pitch. The purpose of this article is to present the historical development of these tests in the psychological laboratory of the State University of Iowa, to describe them in their present form, and to suggest some of the experimentation still necessary for their standardization. The tonoscope itself has been fully described by *Seashore* (6).

Historical

In 1905, *Seashore and Jenner* (5) carried on experiments to answer two questions: (1) Can we facilitate development of control in the pitch of the voice by using an aid to the ear in training? (2) May the ordinary limits of accuracy be exceeded by training with such aid? Their data were gathered from three measurements made by means of the tonoscope: (1) accuracy in reproducing a given tone; (2) accuracy in singing a required interval; and (3) the least producible change in the pitch of the voice. The standard or fundamental tone was 100 d.v., produced by a large tuning fork. The intervals were the major third, the fifth, and the octave above this, sung by the subject without having them previously sounded for him. The least producible change was determined from each of these four tones (1) in the least producible sharp, and (2) the least producible flat, from the

note as actually sung. Each period of practice consisted of 160 trials which took about forty-five minutes. The tests continued twelve days, approximately successive. During the first five days the singer depended entirely on the ear as in ordinary singing; then followed five days of singing with aid, *i.e.*, the observer was informed of the result of each trial immediately after it was made. The records of the eleventh day were taken without aid, while on the twelfth day aid was again given. Six men acted as observers.

Somewhat abridged, the conclusions are as follows:

"(1) The aid enhances the ability to strike a tone which has been heard. The superiority of the aided series over the unaided amounts to 42 per cent. (2) The aid enhances the ability to sing an interval. The superiority of the aided series over the unaided amounts to 50 per cent for the major third, 50 per cent for the fifth, and 60 per cent for the octave. (3) The voluntary control of the pitch of the voice is improved by aid. The average superiority of the aided series over the unaided for all intervals amounts to 26 per cent. (4) There is probably some transfer of gain from the aided training to following unaided singing. (5) There is no evidence of transfer of gain in the accuracy of the memory image. . . . (6) The gain in the discriminative control of the pitch of the voice is fully transferred. (7) Improvements in the ability to sing a tone or an interval and the ability to produce a minimal change are very much more pronounced and more rapid in the aided than the unaided series. . . . (9) The major third, the fifth, and the octave are approximately equally difficult intervals to sing. . . . (10) The minimal change is a relatively constant fraction of a tone within the octave. This is true for both the aided and the unaided series. If we reduce the records from vibrations to twenty-fifths of a tone, the minimal change is 3.1, 3.1, 3.6, 3.3, for the fundamental, the major third, the fifth, and the octave respectively. . . ."

In 1913, before beginning an intensive study of the accuracy of the voice in simple pitch singing, *Miles* (3, p. 37) carried on a series of preliminary experiments "concerning some factors which must be considered in any adequate test of voice control." (1) How does accuracy of control vary with the range of the voice? (2) How does the intensity of the standard tone affect the pitch reproduction? (3) What is the relation of voice volume to voice control? (4) Are the reproductions affected by the timbre of the standard tones? (5) Do vowel changes in the reproductions cause changes in the pitch of the reproduction? His findings may be summarized as follows:

(1) Accuracy in the production of the pitch of a tone tends to be a relative constant throughout the tonal range; (2) increase in intensity of the standard causes a lowering in the pitch of the reproduction, and strong standard tones

cause general inaccuracy of voice control. The just clearly perceptible tone is most favorable for accurate results; (3) increased volume of tone in the reproduction brings about a tendency to sharp; (4) reproductions of rich tones are more accurate than those of pure. But "while tuning forks, being relatively pure and free from overtones, are at a disadvantage on the side of richness, it is also true that in most groups the observers are about equally unpracticed in singing with forks, which is an advantage from the standpoint of measurement. The forks are decidedly more constant in pitch than any other type of standard tone." The best vowel quality for reproduction is a as in "ah."

Profiting by these results in planning the rest of his experiments, Miles proceeded on an intensive study of accuracy in singing. The main problems of his research were: (1) What is the average error of the human voice in reproducing the pitch of a tone? (2) What is the average minimal producible change of the voice? (3) Is there any general tendency to sing flat or sharp? (4) How does the average performance of men and women compare on the above three points?

His apparatus and method were as follows: With the aid of the tonoscope, eleven large disc forks were tuned to the pitches 128 d.v., 128.5 d.v., 130 d.v., 131 d.v., 133 d.v., 136 d.v., 140 d.v., 145 d.v., 151 d.v., and 158 d.v. The series of pitch increments between the forks was therefore: .5, 1, 2, 3, 5, 8, 12, 17, 23, and 30 d.v., as measured from 128 d.v. This series of tones was used for men. For the women a second set was provided on 256 d.v. as a basis, namely, 256, 256.5, 257, 258, 259, 261, 264, 268, 273, 279, and 286 d.v. Koenig resonators were provided for each set of forks. As the increments were small it was found that one resonator would speak sufficiently well to several tones. In the case of the 128 set, three resonators were used. For the higher set two resonators were found sufficient. Both series of forks as reinforced by the resonators gave tones of pleasing quality and medium intensity.

The test consisted of recording the ability of the observer to imitate the tones as presented to him by the forks. The standard tone was designated "0," and the forks presented in pairs. A few preliminary trials were given on increment 0–30 in order that the observer might find himself becoming familiar with the tonal range covered by the standards as well as the experience of

taking pitch from a tuning fork. The series was then given in pairs in the following order: 0–23, 0–17, 0–12, 0–8, 0–5, 0–3, 0–2, 0–1, 0–.5, 0–.5, 0–1, 0–2, etc., back to 0–30. The complete test consisted in singing the series through five times. The tests as outlined could not be performed with care in less than thirty minutes. From the record of two hundred tones secured from each individual, the average error in singing the standard, singing the interval, and the least producible change were computed.

From his results, Miles was able to make valuable recommendations toward a standard test. Somewhat abridged, they are:

(1) The ability to reproduce pitch and the ability to produce voluntarily small changes sharp or flat in the pitch of the voice may be tested together with advantage. Neither of them should be taken in combination with such factors as accuracy of tone memory or judgment for musical intervals. (2) Use a graded series of standard tones similar to that commonly employed in testing for pitch discrimination. (3) Use tuning forks for standards. (4) Begin with the largest pitch increments and proceed to use smallest and then in reverse order back to the largest. (5) Give the tones in pairs, presenting the variant tone immediately after the reproduction of the standard, thus securing a rapid adjustment which favors discrimination in the kinaesthetic sensation from the larynx. (6) Control conditions: (a) The forks should be presented before resonators which are some distance from the observer and care must be exercised to present them with uniform intensity. (b) The observer should use a medium volume of voice in singing the tones. (c) The experimenter should select the vowel to be sung and insist on a good quality. (d) If time intervals are used between standards and reproductions they should be short, not longer than two seconds at most. (e) Time intervals should be introduced between pairs of tones. These should be at least two seconds in length. (f) Secure effort on the part of the observer who is too easily satisfied with his own performance.

In "*Some factors in musical talent and training,*" by *Seashore and Mount* (4), we find a description of the tests of singing key, singing interval, and voluntary control of pitch as given in '09, '11, and '16. To quote from the article:

"Singing the keynote ('09, '11, '16): Singing the keynote was measured in terms of the average error in reproducing the standard tone sounded by a tuning fork before a resonator. In most cases the standard was 256 d.v., the women being allowed to sing this pitch, and the men an octave lower. . . . The measurement was not made in and of itself, but was taken from the singing of the keynote in singing intervals, scales or minimal change. . . .

"Singing the interval: In '09 the test consisted of the singing of the three intervals, the major third, the fifth, and the octave after sounding the keynote

in each trial, the measure being in terms of the average error, as calculated from the standard as sung rather than as sounded by the keynote.

"In '16 this test consisted of the singing of the first two phrases of 'America,' record being made of the average error in the sounding of the notes which occur for the words 'my,' ''tis,' 'sweet,' 'of,' 'sing.'

"Voluntary control of pitch: This is the measurement of the least producible difference, or the minimal change in sharp or flat as described by *Miles* (3, p. 54)."

In 1918, Dr. Gaw included these three tests in a long series of measurements which she made on twenty-six music students in the conservatory at Northwestern University. The instrument used was a small portable tonoscope, which works on the same principle as the large one described by *Seashore* (6).

In this series of tests, the tonoscope was tuned exactly to a 290 d.v. fork which made the fourteenth row of dots stand perfectly still. The fork was then sounded in the resonator so that the observer could hear it distinctly. For the measurement of singing key and also of control of voice the observer tried to reproduce the same note on the tonoscope, holding it half a second, and immediately without change of breath singing another tone slightly higher than the keynote. Each observer was told to make the interval smaller than half a tone if possible, and this interval was sung for her. She was told the result of her trials, and was constantly urged to make the interval smaller. In the same manner ten trials were taken again with the fork sounding the keynote, but the observer sang this time the keynote and a very small interval lower than the keynote.

For the measurement of singing interval, the observer sang two measures of America, after the fork had been sounded as a keynote. By recording the reading of each of the notes as sung, three readings of the keynote, one of the leading tone, and one of the second, were obtained. This was supplemented by a test in the singing of the major third. Each observer was given the keynote by means of 265 d.v. fork. The observer sang the keynote and the major third above, repeated the third, and ended again with the keynote. The results will be recalled later.

The record of measurements made on the small tonoscope is in terms of the number of the row standing still. The record must therefore be translated into terms of vibrations before the results

can be interpreted. Dr. Gaw did this by finding the average error of the row-number in singing key, and the average difference between the row-numbers in voluntary control of pitch, then multiplying this average by 1.25, which is the theoretical difference in vibration from one row of the tonoscope to the next. In order to determine results for singing interval, the average errors for each note recorded in the melody were averaged, and this multiplied by 1.25. The other part of the interval test is computed in the same manner (1).

Present Form of the Tests

The tests in their present form were given to sixty students of elementary harmony in the music school of the State University in 1921, to ten advanced students in 1922, and to thirty elementary students in 1923. The tests were given the first two years by the writer, and the third year by Miss Estelle Windhorst. The method was essentially the same for all three groups.

Apparatus and method. Since the tonoscope requires, for its operation, a room that is practically dark, the small tonoscope was set up in the light-and-sound-proof room of the psychological laboratory in 1921 and 1923, and in a larger experimental room, which can be made sufficiently light proof for this type of experimentation, in 1922. The latter setting is to be preferred, in the opinion of the writer, on account of better air and also a more familiar environment. While a great many of the students were in no way disturbed at the "dark-room," for some of them it was reminiscent of childhood terrors. Impatient as one may be with that type of mind, it nevertheless occurs, and must be reckoned with in judging, and securing, results.[1]

[1] In this series of tests, an electric pilot light for the acetylene flame was used. Direct current was sent through two 60-watt lamps to a brass arm on a manometric capsule, and to a flexible strip of brass which might be placed in contact with the brass nipple of the gas-jet tube by a touch of the experimenter's hand. To serve its purpose as a switch, this brass strip was insulated to within an inch of the end. When the circuit was completed by the contact of the brass strip with the gas-jet nipple, the spark produced by the contact lighted the acetylene flame.

The latest device for a stroboscopic light for the tonoscope is described by Metfessel in this volume. [Editor.]

The observer sang into a small brass mouth-piece attached to a rubber speaking-tube. He was instructed to clasp the bell-shaped mouth-piece with his little finger, allowing the rest of his hand to extend beyond and amplify it. While singing, he was told to rest his lips against his hand. By clasping the mouth-piece tightly with the little finger, and holding the rest of the fingers less tightly clasped, a clear reading usually resulted when the lips were placed in the hollow made by the thumb and fore-finger and the tone sung on the syllable "ah." Care had to be taken that the observer did not open his mouth wider than the opening in his hand, as this diffused the tone and made the reading very blurred and gray.

It was important that the reading be kept clear and black for accurate work. In fact, securing clear readings is the most important and the most difficult phase of tonoscope testing. This was especially true in testing women. Their voices do not register as easily as those of the men, and if the observer was of the hysterical, nervous type, often fifteen minutes were wasted in securing the first clear reading by a proper voicing. After this appeared, the rest of the test was accomplished with more ease. But when, after repeated endeavor, the tone sung still did not show clearly, the observer became irritated and impatient with the apparatus, rather than with himself, and rarely made a good record in the test. It was interesting to note that this difficulty usually occurred among the students whose intelligence ratings, as measured by the Thorndike test for high school graduates, was below average. The more intelligent students who grasped the procedure quickly gave accurate and definite results with half the expenditure of energy on the part of experimenter and observer.

The speed of the phonograph was regulated so that when a 288 d.v. fork was sounded in the tube by means of a large resonator the thirteenth row of dots stood still. By computing the intervals for the tempered scale, with d reading at row 13, e read at row 27, and f♯ at 41.

Singing key and control of voice. The 288 d.v. tuning fork was struck and held close to the ear of the observer. As soon

as he heard it clearly he was told to sing that tone on the syllable "ah." The men sang an octave lower, 144 d.v. After a few moments of practice, the observer was told to sing that tone, and then immediately, without change of breath, to sing a tone which would be as little above that as he could sing. Several trials were allowed before the notes were recorded. Ten trials of this were given, the standard having been sounded every time before the keynote was sung. Then the observer was told to sing the tone the least below the standard that he could. There were also ten trials of this, with the fork sounded before each trial.

Singing interval. This was measured by means of the major third as it occurs in the first four measures of "America." This melody was chosen rather than any interval per se, for it is conceivable that there are persons who would be at a complete loss if requested to sing an absolute interval, but who could sing without difficulty this most familiar tune, if they are able to sing at all. Also, the melody presents the interval as intervals actually occur in singing, and not under test conditions alone. The melody was sung on the syllable "ah." For about half the hundred cases under discussion, the first d, the second e, the third f, and the last d (key of d) were recorded. But since this seemed unnecessary in computing results, the consumed valuable time in the test, in the remainder of the tests only the first d (my) and the first f (sweet) were recorded.

Singing the keynote. The ten trials occurring at the beginning of "America" were averaged with the twenty trials of the standard tone sung in the test of least producible change, and the standard, 143.4 d.v., subtracted from this average. This gave the average error in singing keynote.

For the *least producible change,* voluntary control of pitch, the standard was subtracted from the higher or lower tone sung, and twenty differences averaged. This gave in d.v. the smallest difference actually sung.

In *singing interval,* the standard as sung (d) was subtracted from f♯, as sung. The ten differences were averaged, and the difference, without regard for sign, between this average and

35.8, the correct number of d.v. between d and f♯, determined. This figure is the average error in singing interval.

The norms used are derived from the records of 129 men and 156 women, tested by *Gaw* (1) on the large tonoscope in 1916. The norms for Singing Key and Voluntary Control were made in 1916 by Dr. Gaw. The norm for singing interval was made in 1920 from Dr. Gaw's data, by the writer.

Discussion of Some Factors Involved

Singing key. The simplest of the three tests from the observer's standpoint is singing key. All he is required to do is to imitate a tone which is sounding on a tuning fork. But the very simplicity of the test gives rise to a complication. *Miles* (3) comments on a tendency which the writer has found to be very frequently true:

> "Observers, when making successive trials on the same standard, very often reproduce their own reproductions rather than make the new efforts at imitating the real standard. The observer finds it much easier to reproduce his own previous tone, duplicating the muscle tension and mouth resonance which he experienced at that time and felt to be satisfactory. Indeed, even though he conscientiously work against this tendency, he cannot overcome it entirely if engaged in making successive trials where the pauses between are brief. This is confirmed by the fact that frequently when observers for some cause or other have been dissatisfied with attempts and desired new trials given them immediately, they would in the new trials unconsciously repeat the identical pitch given before."

Knock (2) also says:

> "The tuning fork is found to be far the most difficult, and one's own voice the easiest to reproduce. In explaining this, one must take into account the actual differences in tone quality, the differences in familiarity with the respective tones, the differences in location, the differences in volume; but most of all the rôle of kinaesthetic imagery and kinaesthetic sensations."

Thus in giving the test of singing key it is far better to combine it with singing interval or voice control, since in so doing, no tone is sung twice in succession. Even with the alternation of tones in the latter test, the same thing occurs, and the observer finds it very difficult to shift from the tones he first sang.

Voluntary control of pitch. The test, the results of which are most difficult to interpret, is that of voluntary control of pitch.

The ranks for this group of one hundred students rated by Dr. Gaw's norms are startingly high. It may be objected that this is a selected group, one whose ranks could be expected to be high by virtue of the fact that they are music students, accustomed to singing, if not the possessors of trained voices. Remarkably high ranks in voluntary control were received by students who made the lowest ranks of the group in the other two singing tests. For example, one man receiving rank of 100 in voluntary control of voice, ranked 22 in singing key, and made a record so low in singing interval that he had to be ranked 0. Twenty of this type of inconsistency, though not so extreme, are found in her report.

In the opinion of the writer this apparently superior control is in some cases rather a lack of control. That is, the observer is told to make the least difference he can between his tones. His voice becomes "set," in the manner discussed under singing key. He gets in a key-tone rut, from which he cannot consciously escape. Variations in his tone of .5 to 4.5 d.v., and even more, do not take place because he wills them, and he is often unconscious of the fact that he is making any difference at all between the tones. When asked whether he is singing sharp or flat (higher or lower) from the original tone, his answer is "I don't know." There may be possibilities of training such a person in voice control as shown by the very small differences he actually sings. However, these are not voluntary differences, and it is a misnomer to call them so. This person is less skilled than the one who consciously and intelligently sings very small differences, and the two should not receive the same rank.

Miles' recommendations toward a standard test are worth recalling at this point. He advocates for such a test the use of a graded series of tones similar to that commonly employed in testing for pitch discrimination.

"Such a series has obvious advantages over the use of a single standard; (1) If several observations are to be made at a single sitting the effects of practice are not so great. (2) The small pitch intervals make clear to the observer what he is expected to do with his voice. (3) The variety of standards (and hence degrees of difficulty) reduce monotony and fatigue. A graded series furthermore has advantage over any other series: (1) it keeps

the test comparatively free from complication with the singing of musical intervals, and (2) when the standards represent small steps of pitch difference, the observer discriminates more carefully and is not so likely to be satisfied with a mere approximation" (3, p. 63). Also: "The increments from 0–30 to 0–5 serve to work down the voice, to make clear to the observer what is to be done, and to center his attention for most careful control. The four smaller increments 0–3 to 0–.5 are the place where the ability to make faint shadings is really tested and under usual conditionc the reproductions on the smallest increment, 0–.5, would seem to give the best measure" (3, p. 57).

Such a test would take more time than the one that is given now. It would involve skill in presenting a series of forks in pairs rapidly enough for satisfactory work in a darkened room, and reading and recording the tones sung at the same time. But its principle is more satisfactory, for the reasons stated above, than that of the test now in use, and the latter should be revised with these factors in mind.

Singing interval. Another unusual distribution of percentile ranks is found in the results of this test. There are more very low ranks and very high ones than would ordinarily occur. Until there are more reliable norms, it is impossible to say whether this is the result of chance, or whether there are actually two outstanding classes of people revealed by the test, *i.e.*, those who can, and those who cannot sing intervals truly.

The test as it is now given is the most satisfactory of the three to use. There is little danger of the voice falling into a "rut"; there are but two notes in the melody to be read by the experimenter with meticulous care, which allows the observer to sing at a normal tempo, instead of one far slower than ordinary; and the observer is at ease in the melody. The objection may be raised that the interval measured does not occur directly in the melody, *i.e.*, that other notes interpose between the d and the f♯. This is of no great moment, since whether conscious or unconscious, the singer's feeling for tonality is so strong in such a familiar melody that he will place each note with reference to the "home-point," that is, the d. By measuring the interval as actually sung, allowance is made for a tonic that is either flat or sharp.

Inter-relation of the Tests

Seashore and Mount presented in 1918 some inter-relationships of musical capacity tests, as shown by the r of the Pearson product-moments formula (4). Their correlations between the three singing tests and between these tests and pitch discrimination and tonal memory are presented in the following table. For comparison these same relationships as determined from the combined tonoscope records of 1921, 1922 and 1923 are also presented in the table. The 1916 figures are based on about 225 cases, the 1921 on 100 cases.

TABLE I. *Correlations*

		Singing interval	Voluntary control	Pitch discrimination	Memory
Singing key	1916	.61±.03	.55±.03	.21±.04	.32±.04
	1921	.35±.05	.14±.06	.25±.06	.22±.06
Singing interval	1916		.32±.04	.22±.04	.30±.04
	1921		.16±.06	.21±.09	.30±.06
Voluntary control	1916			.38±.04	.50±.03
	1921			.28±.06	.38±.05

The left-hand figure in each pair is the correlation (r), the right-hand, its probable error.

The correlations are all too low to warrant any but the most general conclusions. The only 1921 correlations which definitely indicate relationship are those between singing key and singing interval, voluntary control and tonal memory. In commenting on the 1916 correlation between singing, and singing the key note, Dr. Seashore says: "Singing interval, singing the scale, and voluntary control involve the same factors as singing the key, plus the interval concept and memory for this concept. This correlation shows that, as a rule, those who can sing the key at all accurately tend to sing the interval accurately" (4, p. 14). The difference between the 1916 correlation and that of 1921 is probably due to the difference in the technique of giving the test of singing interval and the manner of interpreting results. In 1916 each note sung in the first two measures of America was recorded. The average error for each note was determined, these were averaged, and the resulting figure wos the average error in singing interval. In this method it will be seen that no allowance

was made for the observer who sang the melody throughout with each note uniformly flat or sharp from the standard notes. His average error would be large, while as a matter of fact, the actual intervals he sang might be entirely accurate, provided the amount he flatted or sharped was uniform for each note. This method of interpreting error differs little from that employed in the test of singing key note. In this test the results are in terms of average error, with relation to the standard tone. It is easy to understand that there might be a high correlation between two tests whose principles are so closely allied.

In 1921, in the test of singing interval, only the first d and the first f♯ of the melody were recorded. In interpreting results, the d as sung was subtracted from the f♯ as sung, and the average error determined between this figure and that of the standard interval. This process has less in common with the procedure of singing key than the 1916 method had, and we should expect a lower correlation.

Dr. Seashore dismisses the correlation (1916) of $.50 \pm .03$ between voluntary control and tonal memory with the simple statement: "This accords with introspections" (4, p. 77). The writer wonders if this could not be amplified by supposing the introspections to deal with the common kinesthetic element in the two tests. How much of our tonal memory is kinesthetic? And does not voluntary control of voice, to judge by the available testimony of observers and experimenters in tonoscope singing, seem to depend largely on the kinesthetic element?

Our greatest lack in commenting upon correlations between the singing tests is any criterion on which to base judgment of their meaning. Perhaps a low correlation between the tests is a better indication of their serviceability than a high correlation would be. Perhaps the factors involved in these three tests are unrelated, and each should stand by itself. If so the tests are in more adequate form to-day than they were in 1916. On the other hand high correlation between the tests may be our safest basis for pronouncing them efficient. If this be true we are farther from our

goal than we were in 1916. With our present lack of criteria there can be only speculation as to the answer to this problem.

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